VAN NOSTRAND'S

ENGINEERING MAGAZINE.

NO. CXXVII.—JULY, 1879.—VOL. XXI.

THERMODYNAMICS.

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Written for VAN NOSTRAND'S MAGAZINE.

V.

49. CLEARANCE AND COMPRESSION.—In Figs. 7 and 8, let 4′ 2′ be the length of stroke of the piston of a steam or hot air engine; then 4′2′ may be taken to represent the volume swept through by the piston. Let o4′ be the volume of the clearance on the same scale, *i.e.*, the smallest volume which can be enclosed between the steam valves and the piston. The greatest volume which can be enclosed between the steam valves and the piston is then o2′, which is the actual volume of the cylinder. Let 12340 be the ideal indicator card of the engine, by which is meant such a card as might be got if the valves opened and closed instantly instead of gradually, and they afforded no resistance to the passage of the steam.

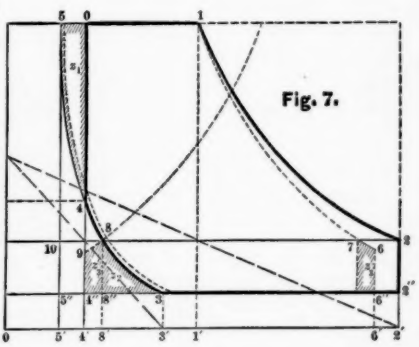


Fig. 7.

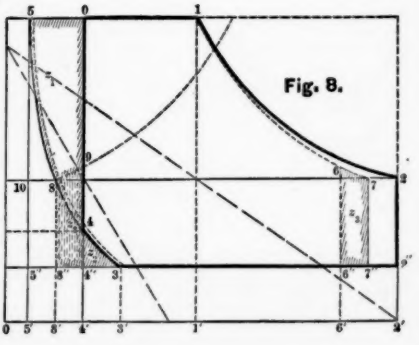


Fig. 8.

Then, $11' = p_1$ = pressure of admission, or forward pressure.

" $22' = p_2$ = pressure of release, or terminal pressure.

" $33' = p_3$ = pressure of exhaust, or back pressure.

" $44' = p_4$ = pressure of compression, or initial pressure.

" $o1' = v_1$ = total volume of steam expanding from p_1.

" $o2' = v_2$ = total volume of steam expanded to p_2.

Then $o3' = v_3$ = volume of cushion steam at p_3.

" $o4' = v_4$ = volume of clearance.

" $o5' = v_5$ = volume of cushion steam at p_1.

" $1'5' = v_1 - v_5$ = volume of working steam at p_1

" $2'4' = v_2 - v_4$ = stroke, or apparent volume of cylinder.

$\frac{v_1 - v_4}{v_2 - v_4}$ = apparent cut-off of expansion.

$\frac{v_1}{v_2}$ = real cut-off of expansion.

$\frac{v_3 - v_4}{v_2 - v_4}$ = apparent cut-off of compression.

$\frac{v_3}{v_2}$ = real cut-off of compression.

$\frac{v_2}{v_1}$ = real ratio of expansion.

$\frac{v_3}{v_4}$ = real ratio of compression.

In order to discuss the effect of the clearance upon the working of the engine, we shall compare this indicator card with that of an engine having a cylinder in which the piston sweeps through the same space during each stroke, and uses the same quantity of steam per stroke, but which has no clearance at all. The ideal indicator card of the cylinder without clearance is used as a standard of comparison, because clearance-space necessarily involves a loss of efficiency in any practical case, as may be seen readily from the following considerations, which hold in case the release is at a terminal pressure p_2, greater than p_3 the back pressure during the exhaust. As shown in art. 32, the clearance causes no loss of efficiency when the expansion is carried so far that the terminal pressure is the same as the back pressure, but when the release occurs at some pressure greater than the back pressure, as at p_2, then all the external work which would have been performed by the cushion in expanding from p_2 to p_3 is lost, for it must be expended during the corresponding compression from 3 to 8.

Let $5'6' = 4'2'$ be the stroke of the piston in a cylinder without clearance which is supplied with the same quantity of boiler steam $5'1'$ per stroke. The ideal indicator card of no clearance, with the given forward and back pressure, is $166''5''5$, and this is the card which we wish to compare with 12340.

It is to be noticed that the line $55'$ is that from which volumes are to be computed in the card with no clearance, and hence, the expansion curve 16 falls below 12. Let 16 cut the horizontal line through 2 at same point 7, which may be either at the right or left of 6.

Let us first compare the part of the two cards which is above the horizontal 82. The areas 1 2 7 and 5 8 10 are equal because they respectively represent the work of expansion and of compression of the cushion. Hence above 82 there is work performed in case of no clearance which is not performed with clearance to an amount represented by 540 in Fig. 7, and 580 in Fig. 8, for this amount is lost above 82 from the card with no clearance by reason of introducing the clearance. But it is of no consequence whether 4 is above or below 82, there is a loss in any case of 540, since it lies outside one card and within the other.

Next we notice that below 82 the area $388''$ is lost by reason of clearance, it being the work necessary to compress the cushion from p_3 to p_2.

There is also one other area $76''$ which may represent either a loss or a gain due to clearance.

In Fig. 7 we have compared all parts of the two indicator cards except that included in the equal rectangles $72''$ and $85''$. The rectangle $85''$ is lost work of compression. The equal rectangle $72''$ is work gained by clearance except the bordered area $76''$ which being found in both cards cannot be credited to clearance. Therefore lay off $894'' = 766''$ and we then have the total loss by reason of clearance in Fig. 7 to be

$$z = z_1 + z_2 + z_3 = 540 + 3894'' \ldots . (292)$$

In order to construct $84''$ most readily, draw the expansion curve 76 in reverse position at 98, considering the stroke of the piston to be $4'2'$, as it really is.

In Fig. 8 the work of compression $585''$ is equal to $1727''$, and there is a gain due to the clearance of $676''$, for the card with no clearance extends only to 6. If

this area 76″ be laid off under 98 at the left in the darkly shaded area, it is seen that this gain cancels part of the loss before enumerated, so that the total loss in this case is

$$z=z_1+z_2+z_3=5890+344'' \ldots (293)$$

We must take z_3 positive when 6 is below 82 and negative when 6 is above 82.

From an algebraic point of view, (292) and (293) are identical, and the two cases are separately figured only for a more complete understanding of the subject.

In order to find the point 3 for the cut-off of compression which will give the best efficiency for a given forward and back pressure with a given stroke and a given cut-off of expansion, it is necessary that the losses enumerated should be a minimum. If the point of cut-off 3 be slightly moved to the right as is indicated by the dotted line near 35, it is seen that the loss along this curve from 4 to 5 is diminished by so moving it, but that that from 3 to 8 is increased. It is easy to express the magnitude of these increments of the loss when we know the equations of the expansion and compression curves.

As before remarked near the end of art. 46, the curve of the rectangular hyperbola is a sufficiently close approximation for the purposes of geometric treatment of the expansion curve of steam, and questions like the present one relating to external work are solved in more simple terms, in case the expansion is thus assumed to be in accordance with Mariotte's law, than in case we use curves theoretically more exact. For the present purposes the assumption that the expansion curve is the rectangular hyperbola is sufficiently exact. Hence, making use of (272) we find the differential co-efficient of z_1 with respect to v_3 thus:—the work of compression under 45 is,

$$p_4 v_4 \log_e \frac{v_4}{v_5} = p_3 v_3 \log_e \frac{p_3}{p_4} \ldots (294)$$

$$\therefore z_1 = p_1(v_4 - v_5) - p_3 v_3 \log_e \frac{p_3}{p_4}$$

$$\therefore z_1 = p_1 v_4 - p_3 v_3 \left(1 + \log_e \frac{p_1 v_4}{p_3 v_3}\right) \ldots (295).$$

$$\therefore \frac{dz_1}{dv_3} = -p_3 \log_e \frac{p_1 v_4}{p_3 v_3} = -p_3 \log_e \frac{p_1}{p_4} \ldots (296)$$

Similarly also,

$$\frac{d(z_2+z_3)}{dv_3} = +p_3 \log_e \frac{p_2}{p_3} \ldots . (297)$$

$$\therefore \frac{dz}{dv_3} = p_3\left(\log_e \frac{p_2}{p_3} - \log \frac{p_1}{p_4}\right) \ldots . (298)$$

In order that z may be a minimum, (298) must vanish

$$\therefore \frac{p_4}{p_3} = \frac{p_1}{p_2}, \ \therefore \frac{v_4}{v_3} = \frac{v_1}{v_2} \ldots . (299)$$

which result may be stated in words by saying that the best adjustment of the compression is effected when the real ratio of the compression is equal to the real ratio of expansion.

This result may be expressed in another instructive way. The work of expansion of the cushion steam is

$$127=5\,8\,10 = p_2 v_5 - p_3 v_3 \left(1 - \log_e \frac{p_1}{p_4}\right) . (300)$$

and the lost expansion of the cushion is

$$z_3 = p_3 v_5 - p_3 v_3 \left(1 - \log_e \frac{p_2}{p_3}\right) . (301)$$

By the help of (299) it is seen that (300) and (301) are equal, hence the cut-off is adjusted most advantageously when the work obtained from the expansion of the cushion is equal to the work of the cushion lost by reason of the release. These quantities both vanish in case of no clearance. The proportion expressed in (299) is readily constructed graphically, as shown by the oblique lines on Figs. 7 and 8. These oblique lines cut off distances of v_1 and v_4 on the pressure line p_3, and of v_2 and v_3 on the line of no pressures, such that v_3 is the best cut-off, as appears by proportion of triangles. It is seen that the compression is so adjusted in Fig. 7 as to give the greatest efficiency, but is arranged far otherwise in Fig. 8.

If we designate volumes measured from 04, (the line of apparent zero of volumes) by primes, we have

$$v_1 = v_1' + v_4, \ v_2 = v_2' + v_4, \ v_3 = v_3' + v_4 . (302)$$

$$\therefore \text{ by } (299) \frac{v_2'}{v_3'} = \frac{v_4(v_2' - v_1')}{v_3(v_1' + v_4)} \ . \ . \ (303)$$

which expresses the best apparent cut-off. The foregoing result is confessedly approximate, and may be modified by using a more exact expansion curve as well as by the effects of wire drawing, condensation and re-evaporation in the

cylinder, but like all maxima and minima determinations, is a most useful guide to assist the judgment in practical design.

The approximate area of the indicator card 1 2 3 4 0 will be readily found in case of best efficiency to be

$$p_1v_1+p_2v_2-p_1v_4-p_3v_2 + (p_1v_1-p_2v_2)\log_e\frac{v_2}{v_1} \quad . \quad . \quad . \quad . \quad (304)$$

which is obtained on the supposition of hyperbolic expansion and compression.

The preceding discussion was first given by W. Hartnell,* and was afterwards worked out independently by J. Macfarlane Gray,† but both these discussions are given in such abbreviated form and appear to be so insufficiently explained that their validity seems to have been overlooked, although G. W. Macalpine ‡ has shown that Hartnell's results can be deduced from Gray's.

It is possible to conduct the investigation of the effect of clearance by still a different method. We can show how the compression must be arranged in order to get the greatest external work per pound of steam, with given clearance, given expansion, and given forward and back pressures. Cotterell § has, in his valuable treatise, investigated the problem in this manner, but the results, which can differ from those just obtained by only an insignificant amount, are not characterized by simplicity of conception or expression. An editorial discussion of the subject after this manner is to be found in *Engineering*, Vol. XIX, p. 41, in which it is proposed to simplify the practical solution of the question by the help of certain auxiliary graphical curves.

Theoretically it would appear that steam should be expanded in the cylinder until the pressure of release is reduced to the back pressure of the condenser, but this is far from being the case when the expansion takes place in a metallic cylinder. During such an expansion the temperature of the expanding steam and the metal in contact with it is so reduced that a notable amount of boiler steam is condensed on the metal at the beginning of the next stroke in nate heating and cooling is a process of supplying heat at a high temperature order to heat the metal, which heat is again restored during the latter part of the stroke in re-evaporation. This alter- and restoring it at a lower temperature, without performing the work which by the second law might be performed during the fall of temperature. In order to limit this loss, it is necessary to restrict the degree of expansion in single cylinders within comparatively narrow limits, though the use of a steam jacket has a most beneficial effect in diminishing the amount of surface condensation. The most serious effects of this kind are to be found at the ends of the cylinder, as at those points are the greatest continued alternations of temperature. And especially do the cylinder heads need jackets more than the sides of cylinder. No device has, it is believed, been yet applied to the piston to supply it with heat, but it seems quite practicable to have the exposed surface of the cylinder and piston heads covered with some non-conducting material. Were this done, I am led to believe that much more than fifty per cent of the condensation and re-evaporation would be obviated. I am informed that with this end in view, cylinder heads are now constructed for the best engines which contain a layer of asbestos. The pistons should be constructed in a similar manner.

50. Compound Engines.—Various practical difficulties attend the use of steam at high pressures, among which, in addition to condensation and re-evaporation just mentioned, one of the greatest of these is due to the irregularities of pressure during the stroke. Steam admitted at a high pressure during one tenth or some less fraction of the stroke, and expanded during the rest of the stroke, exerts most of its energy so near the beginning of the stroke that the mechanical effect approximates in character to a sudden blow, or to an explosion, which must be withstood by correspondingly heavy and costly parts.

Compound engines are designed to obviate, or at least palliate, these two difficulties. A compound engine is one in which the boiler steam is used successively in two or more cylinders. In Fig. 9, if the expansion is to be carried from 1 to 5, it is easily seen that the expansion is effected more advantageously

* *Engineering*, Vol. XI, p. 375: London, 1871.
† *Engineering*, Vol. XVII, p. 241: London, 1874.
‡ *Engineering*, Vol. XIX, p. 171: London, 1875.
§ *Steam Engine*, James H. Cotterill, London, 1878.

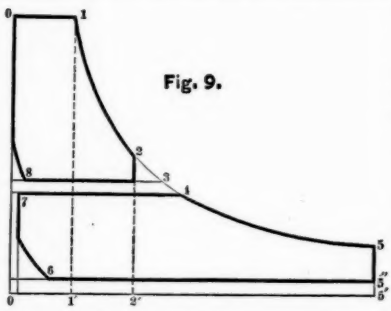


Fig. 9.

in two cylinders than in one. For let 1280 and 4567 be the indicator cards of the high and low pressure cylinders respectively of a compound engine. And let the first cylinder work between the pressures p_1 and p_2 in such a manner that it exhausts at p_2 into a steam reservoir intermediate between the two cylinders, while the second cylinder works between the pressure p_4 of the reservoir, which is a little lower than p_2, and the pressure p_6 of the condenser. It then appears (if 2 is the point of release of the first cylinder) that the ratio of expansion is $v_2 : v_1$, and the cut-off may then be so large a fraction of the stroke as to obviate the difficulties which would occur if the expansion were $v_2 : v_1$, as it would be in a single cylinder. The second cylinder has its cut-off at 4 and its expansion is $v_4 : v_4$ which may also be well within practicable limits. The difficulties of condensation and re-evaporation are partially obviated also, because in the first place the whole range of temperature is divided between the two cylinders so that the range of each cylinder is confined between narrower limits; and in the second place the first cylinder, which is comparatively small, may be alone subjected to the greater range of temperature.

It is quite possible to expand the steam down nearly to 3 in the first cylinder, in which case there is no loss from clearance in the first cylinder if the cushion is compressed to boiler pressure. This permits the valves to be so arranged that there will be little or no loss by throttling, *i. e.* p_3 and p_4 may be almost identical. The only loss from clearance will then be in the second cylinder. It then appears that the losses from clearance in a compound engine can be made smaller than when the same degree of expansion is effected in a single cylinder.

In case there is no intermediate reservoir, the steam is used first to drive the piston of the small cylinder and then it is admitted into the second cylinder, and by its expansion drives the piston. Fig. 10 represents the indicator cards 1260 and 255″2″ of such an engine. It is seen that during the expansion in the second cylinder the back pressure in the first cylinder causes a very considerable loss of work.

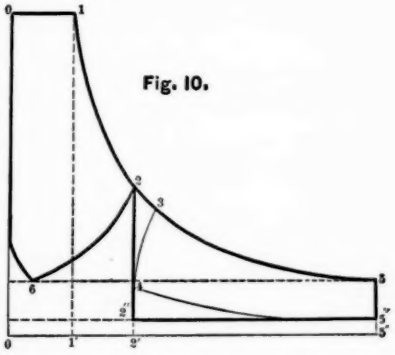


Fig. 10.

It is possible, however, so to arrange the strokes of the two engines as practically to realize the theoretic advantages of a compound engine having indicator cards like those in Fig. 9 with a reservoir of quite inconsiderable volume. A series of valuable papers on this subject may be found in *Engineering*, Vol. XI, 1871, by Hartnell. See also Mallet,* who has discussed somewhat at length the matter of condensation and re-evaporation.

51. Theoretic Efficiency of Steam.—Disregarding the practical losses of efficiency due to clearance, to release at a pressure greater than the back pressure, and to the conductivity of the cylinder and other parts composing the steam engine, we wish to obtain the efficiency of steam as a working substance. The losses just mentioned may be properly disregarded in determining the possible efficiency of steam, because they are merely mechanical difficulties attendant upon the pattern of steam engine now in use, which may be in a large degree overcome in future. But the nature of steam

* *Compound Engines.* A. Mallet. Van Nostrand's Science Series, No. 10. New York, 1874.

itself, as a working substance, apparently renders it impossible that it can ever be employed in a cycle of perfect efficiency according to Carnot's principle. While this is undoubtedly the fact, as will be presently explained, this loss of efficiency, which is inherent in the nature of the substance itself, is much less than has often been supposed, and is not so great as to detract very materially from the efficiency possible by Carnot's principle.

By art. 19, in the cycle of greatest efficiency all the heat supplied must be at the highest available temperature, and all the heat rejected must be at the lowest available temperature, while the passages from the highest to the lowest temperature, or *vice versa*, must be along adiabatics, *i.e.*, must be effected by the expenditure of external work positively or negatively.

Now there are no difficulties inherent in steam to prevent the passage from the higher to the lower temperature adiabatically, or to prevent the occurrence of all the rejection of heat at the lowest available temperature, but it is impossible to raise the temperature of the feed water by mechanical means alone, such as compression, to the highest available temperature. The heat, which is necessarily used in heating the feed-water to the temperature at which it is evaporated, is not applied in the most efficient manner possible; on the contrary, however, the latent heat employed in effecting the evaporation, is employed in the most efficient manner, and as the latter is so large compared with the former, the loss of efficiency is not so great as in fluids having a latent heat relatively smaller. The per cent. of loss from this cause is greater at high than at low temperatures, but the loss is much less for water and its vapor than for any other known liquid and its vapor; the corresponding loss in an ether engine being at least four times as great.

In order to express the maximum possible efficiency of a steam engine, let the state of the exhaust steam be expressed by the subscript 1 and the state in the boiler by 2, then by (223) the heat imparted in raising a unit of the feed water from the temperature of the exhaust to that of the boiler is $c'(t_2-t_1)$. Also by (223) the heat imparted in evaporating a fraction x_2 of this unit is l_2x_2,

$$\therefore\ h_2=l_2x_2+c'(t_2-t_1) \quad . \quad . \quad . \quad (305)$$

is the total heat imparted to each unit.

Also by (223) $h_1=l_1x_1$ . . . . . (306)

is the total heat of condensation rejected after expansion

$$\therefore\ h_2-h_1=l_2x_2-l_1x_1+c'(t_2-t_1) \quad . \quad . \quad . \quad (307)$$

is the external work performed during the cycle, if we disregard the work required to pump the feed water into the boiler.

If the expansion is adiabatic, we have, by (233),

$$l_1x_1=\frac{t_1}{t_2}l_2x_2-c't_1\log_e\frac{t_1}{t_2} \quad . \quad . \quad . \quad . \quad (308)$$

$$\therefore\ h_2-h_1=\frac{t_2-t_1}{t_2}[l_2x_2+c'(t_2-t_1)]+c't_1\left(\frac{t_2-t_1}{t_2}+\log_e\frac{t_1}{t_2}\right) \quad . \quad . \quad . \quad . \quad (309)$$

$$\therefore\ \varepsilon=\frac{h_2-h_1}{h_2}=\frac{t_2-t_1}{t_2}+\frac{c't_1\left(\frac{t_2-t_1}{t_2}+\log_e\frac{t_1}{t_2}\right)}{l_2x_2+c'(t_2-t_1)} \quad . \quad . \quad . \quad . \quad (310)$$

The last term of (310) is essentially negative, for the denomenator is positive and the numerator is negative as appears by expanding the expression in the parenthesis into a series, by the well known formula

$$\log_e\frac{t_1}{t_2}=\log_e\left(1-\frac{t_2-t_1}{t_2}\right)=-\frac{t_2-t_1}{t_2}-\frac{(t_2-t_1)^2}{2t_2^2}-\&c$$

$$\therefore\ \frac{t_2-t_1}{t_2}+\log\frac{t_1}{t_2}=-\frac{(t_2-t_1)^2}{2t_2^2}-\&c. \quad (311)$$

in which all the terms of the expansion are negative.

Hence the last term of (310) expresses the necessary loss of efficiency in using steam as a working substance. The loss is least when the evaporation is complete, *i.e.*, when $x_2=1$; and, though the real efficiency of steam or of any other working substance, is increased by increasing t_2-t_1, yet, as has been before remarked, the loss is a larger per cent. of the efficiency when the range of temperature t_2-t_1 is large than when it is small.

Were it possible to use steam without condensation in the same manner as a gas, the loss of efficiency which has been discussed would not occur.

52. Explosive Gas Engines.—The increasing importance of engines of this kind, and the paucity, not to say the entire lack of any sufficient treatment of the theory of them, leads us, in concluding these thermodynamic discussions, to present that theory in outline, and to make a few remarks upon the relations involved.

The explosive mixture introduced into the cylinder may be regarded from a physical point of view as a perfect gas, and by the explosion, a large amount of heat is suddenly imparted to it in the most effective manner, as appears from the fact that this heat is necessarily distributed throughout the entire mass of the gas. The product of the explosion may also be regarded as very approximately a perfect gas, though indeed part of the product is highly superheated steam or steam gas.

In order to compute the amount of heat evolved by the explosion it is necessary to have regard to the chemical composition of the explosive gas employed, which is ordinary illuminating gas.

The composition of illuminating gas is very variable; its principal constituents are hydrogen and marsh gas, but it contains besides, small quantities of olefient gas and carbonic oxide, together with useless admixtures of carbonic acid gas and air. The least valuable gas for heating purposes which is delivered to consumers, may be taken to consist per cubic foot of the following proportions:

Hydrogen, (H) . . .	0.4 cu. ft.
Marsh Gas, (H_4C) . . .	0.4 " "
Incombustibles, . . .	0.2 " "

1 pound of hydrogen (=179 cubic feet nearly at atmospheric pressure) evolves when burned in the atmosphere from 62000. to 62500. units of heat, *i. e.*, it will increase the temperature of 62000 lbs. of water 1°F. But the steam gas which is the product of combustion has a molecular volume of only two-thirds that of the gases which enter into its composition, hence the heat evolved consists partly of external work done by the atmosphere. Each lb. (=179 cu. ft.) of hydrogen is combined with 8 lbs. (=89.5 cu. ft.) of oxygen to form steam gas which at the same temperature and pressure has a volume of 179 cu. ft. Hence, if the atmospheric pressure is 2116 lbs. per sq. ft. it has performed a work of compression $=2116\times89.5=190000$. ft. lbs. nearly $=310$ thermal units nearly, which quantity may be disregarded in its effect upon the total heat of combustion $=62000$ thermal units. The heat of combustion of 1 lb.$=$22 cu. ft. of marsh gas may be taken at 27000 thermal units. We therefore obtain for the number of thermal units of combustion of the components of 1 cu. ft. of illuminating gas:

179 : 0.4 :: 62000 :	139	nearly.
22 : 0.4 :: 27000 :	491	"
Total.....	630	" thermal units.

Rankine, on p. 447 of his *Steam Engine* has given the results of certain computations as to the heat liberated in the explosion of such a mixture, from which it appears that he assumed the total heat of explosion to be about 660 thermal units, *i. e*,, the 0.2 cu. ft. which has been above assumed to be incombustible was, in the gas he employed, partly combustible.

On p. 152 of Van Nostrand's Magazine for February, 1879,* it is stated that 6000 calories is the heat generated by the combustion of 1 cu. meter of illuminating gas, which reduced to English measure gives about 674 thermal units as the number sought.

It is seen that a larger proportion of marsh gas, and a smaller proportion of hydrogen would increase the total heat of combustion per cubic foot.

In order to compute how much air must be mixed with illuminating gas in order to effect its complete combustion, we notice that each cubic foot of hydrogen requires 0.5 cu. ft. of oxygen or about $2.5\times0.5=1.25$ cu. ft. of air; and each cu. ft. of marsh gas requires 2 cu. ft. of oxygen or about $2.5\times2=5$ cu. ft. of air, hence 1 cu. ft. of illuminating gas consisting 0.4 cu. ft. of hydrogen and 0.4 cu. ft. of marsh gas requires 2.5 cu. ft. of air for its complete combustion. This combustion in a gas engine would not occur completely without the presence of an excess of air, owing to the difficulty of thoroughly mixing the

* Gas Engines at the Paris Exposition, by M. Armengaud, Jr.

gases in the limited time between admission and explosion. It is customary to admit 8 cu. ft. of air to 1 cu. ft. of illuminating gas, and in some cases a still larger quantity.

If we take the weight of 1 cu. ft. of illuminating gas, and 8 cu. ft. of air with which it is mixed at 0.71 lbs., and consider the specific heat at constant volume of the products of combustion to be 0.2 thermal units, we find that were the explosion to take place in a confined space the temperature would be raised by the heat liberated by more than 4500° F. The specific heat of steam at constant volume is 0.37, and that of the other gases is about 0.17. The steam is so small a part of the whole weight that the average specific heat does not exceed 0.2, as assumed above.

Suppose that the mixture were exploded at an initial temperature of

$$39°\text{F.}, \quad \text{or} \quad t_1=461°+39°=500°,$$

and at an initial pressure p_1 equal to atmospheric pressure in a vessel of constant volume $v_1=v_2$, then by Gay Lussac's law, since the final temperature is

$$4500°\text{F.}, \quad \text{or} \quad t_2=4500°+500=5000.$$

$$p_2=\frac{v_1t_2}{v_2t_1}p_1=\frac{5000}{500}p_1=10p_1 \quad . \quad (312)$$

from which it appears that the final pressure is ten atmospheres.

Again let us suppose a slightly different case. Let the explosive mixture be compressed before explosion to half the volume it occupied at atmospheric pressure, and in a hot cylinder, so that its pressure rises by reason of the compression and heat received from the cylinder from 1 up to 3 atmospheres, and its temperature then rises from 39°F. to 289°F. If the explosion then take place at a fixed volume we find as before

$$p_2=\frac{v_1t_2}{v_2t_1}p_1=\frac{4500+750}{750}p_1=7p_1 \quad . \quad (313)$$

from which, since $p_1=3$ atmospheres, we see that the final pressure is 21 atmospheres.

Since the foregoing computations are based upon so low an estimate of the heating power of gas, the pressures and temperatures obtained are likely to be too small.

Were it possible to employ a range temperature of 4500°F., according to the last supposition, we could obtain the efficiency according to Carnot's principle,

$$\varepsilon=\frac{t_2-t_1}{t_2}=\frac{4500}{5250}=\frac{6}{7} \quad . \quad . \quad (314)$$

If the total heat of combustion is 630 then $630\times\frac{8}{9}=540$ as the available heat per cu. ft. of illuminating gas. One-horse power per hour=1980000 ft. lbs. of work=2565 thermal units; hence, 4.75 cu. ft. of gas would, by its combustion, furnish an available horse power of work. Computations similar to these can be readily made for mixtures containing quantities of air either more or less than eight times that of the illuminating gas. Greater proportions of air will involve lower pressures and temperatures after explosion, and *vice versa*.

The foregoing will furnish a basis for the following discussion of an actual engine.

53. The Otto Gas Engine.—In this form of gas engine, the explosive mixture is drawn into the cylinder at about atmospheric pressure, and is then compressed by the piston to $\frac{2}{5}$ of its initial volume. The piston sweeps through only $\frac{3}{5}$ of the total volume of the cylinder, leaving a clearance of $\frac{2}{5}$ its volume. The volume of the gases is not strictly constant during the explosion (which takes place immediately after compression, but the piston sweeps over, at most, $\frac{1}{6}$ of its return stroke before the end of the combustion, so that the total volume occupied by the products of combustion at the instant of its conclusion is approximately $\frac{2}{5}+\frac{1}{6}\times\frac{3}{5}=\frac{1}{2}$ the total volume of the cylinder. This result appears at once from the indicator cards of the engine, which are in general form like that enclosed by the area 55′43 Fig. 10 in which the compression takes place along 5′4, the explosion along 43 and the expansion along 35.

In this engine the cylinder is surrounded by a jacket of cold water which causes the expansion curve 35 to fall more rapidly than that of the adiabatic for perfect gases, for heat is rejected along 35.

The indicator cards to which I have access have an expansion curve whose equation is very exactly

$$pv^{\frac{8}{5}}=p_1v_1^{\frac{8}{5}} \quad . \quad . \quad . \quad (315)$$

i. e., in this engine $n=1.6$ while in the adiabatic for perfect gases $n=1.4$. The compression curve 5′4 may also be taken to have the same equation, hence the external work performed during the expansion, and that expended during compression, may be readily found by (272) and (315). The value of n given above will be modified by the temperature of the water in the jacket and the thickness of the jacket.

In the indicator cards taken from this engine the pressures at 3, the end of the explosion, ranged from 10 to 16 atmospheres absolute in different cards, while the pressures at 4 the beginning of the explosion was about 3 atmospheres absolute.

These results show according to the computations made in the last article, that explosive compound employed did not contain quite so large a proportion as 1 of gas to 8 of air. It appears to be necessary to cool the cylinder, for the intense heat of the combustion would otherwise destroy it, but the mass of the heated gas does not come in contact with the walls of the cylinder, hence, as gas is an imperfect conductor, only a part of its heat is imparted to the cylinder.

It is seen that this engine approximates in its cycle to that of Stirling's air engine without a regenerator, as given in art. 36. The greatest possibly efficiency of such a cycle is that of perfect engine working between the temperatures of the beginning and the end of the expansion. We have computed the temperature of the beginning of the expansion as some 5000° absolute. The release apparently occurs on the indicator cards at 3 or 4 atmospheres absolute, which by Gay Lussac's law would give 1500° to 2000° absolute as the temperature at the end of the expansion. The possible efficiency between these limits of temperature is from $\varepsilon=0.7$ to $\varepsilon=0.6$, which corresponds to a consumption of illuminating gas per horse power per hour, of from 5.8 cu. ft. to 6.8 cu. ft. nearly. The Otto engine actually uses 20 cu. ft. and upwards per horse power per hour, so that apparently two-thirds of the available heat of combustion is wasted by the jacket and by other losses incident to the employment of these excessive temperatures.

One of the principal mechanical difficulties of this kind of engine is the shock at the beginning of the stroke, but it would seem possible to alleviate its difficulties in the same manner as those of high steam at great expansions by the use of compound cylinders, so that the expansion could occur partly in each, as explained in art. 50. It is not known that this has ever been practically tested.

NOTES ON A WATER-COLUMN AIR-COMPRESSOR.

By LOUIS BRUNIN.

Translated from "Revue Universelle des Mines" for Van Nostrand's Magazine.

It is well known that in mines that the streams of water which flow in upon the higher and abandoned levels are generally allowed to fall to the lower levels, from which the water is pumped to the surface. The inventor of the apparatus about to be described proposes to solve the problem of utilizing the power lost by this fall, and to apply the energy to the compression of air.

The principle of the machine is exceedingly simple. It consists in compressing the air in a closed cylinder by direct pressure of the water, which is also admitted. The work of compression is necessarily divided into two quite distinct periods; the first or compression period, during which the water enters and compresses the air; the second or exhaust period, during which the water, having done its work, flows out.

The compressor consists essentially of a reservoir, in the form of a wrought iron cylinder placed vertically, and furnished also with ends of the same metal. Two double-seat valves, A and B, having openings of unequal diameter, serve, one to admit the water during the first period, the other to discharge it during the second.

Two valves, K and L, working inversely to each other, serve to pass the compressed air to a special holder, and to admit, at the proper time, a fresh supply at the ordinary atmospheric pressure.

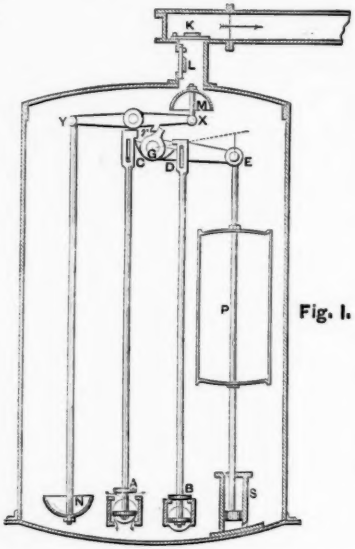


Fig. 1.

At the middle G of a shaft OO′ turning freely in bearings at O and O′, is attached a lever, GE, supporting, by means of a rod, a counterpoise P, formed of a hollow cylinder. The specific gravity of this cylinder is $\frac{1}{2}$, water being unity.

To the lower side of this weight is a rod terminating below in a piston, which works in a cylinder, S.

The shaft OO′ carries two arms or tappets, which work the valves A and B by means of the rods AC and BD.

A little above the shaft OO′, and in the same vertical plane as the lever GE, is a balance XY, of equal arms, each supporting a hollow hemispherical cup, M and N, attached to the rods XM and YN. The cups balance when both are in the air.

The action of the parts above described, under the influence of alternate immersion in water and air, determines automatically the admission and outflow of air and water from the compressor. At the beginning of the compression period the apparatus being filled with air at atmospheric pressure, the counterpoise descends, opening the inlet valve A, and closing the outlet B.

The water enters the reservoir with a velocity depending on its head, and tends to immerse the counterpoise P; its specific weight being only $\frac{1}{2}$, when entirely covered by water, its buoyancy would be equal to its weight, or in other words, it is urged upwards when immersed by a force equal to its weight.

The tendency of the weight to ascend is stayed during the period of compression, by the balance XY, on the lower side of which a tooth r, is held by a stop firmly fixed to the lever GE, as shown in Fig. 1.

At the beginning of the period of compression, while the weight P occupies the lowest position, the water in rising raises the cup N, whose weight is diminished by the weight of the displaced water; by this movement the tooth r is brought to the left of the stop of the lever GE.

As the water rises it compresses the air till the cup M is immersed; this being raised by the buoyancy of the entrapped air (the cup being inverted), the tooth r is carried by the stop, and the lever GE is free to rise.

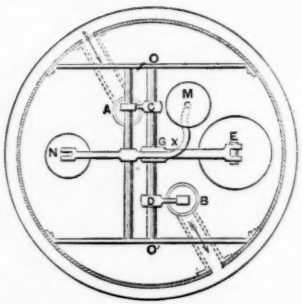


Fig. 2.

At this moment commences the second period—that of the exhaust. The counterpoise P obeys the force which tends to raise it (which is just equal to its weight in air), and by this movement closes the inlet valve A and opens the outlet B.

Soon after the escape of the water begins, when the surface of the water has fallen below the cup M, the latter being in the air will overbalance N, which is still immersed, and the balance-beam will assume the position which it had during the period of compression, only the tooth

r will be to the right of the stop on the arm GE.

The level of the water continuing to descend in the compressor, it will happen that as soon as it is below the counterpoise P, the latter will recover its tendency to fall, but it is now prevented by the resistance of the tooth r, which opposes such movement during the whole period of outflow.

When the compressor is so far emptied that the cup N is above the surface, a new motion of the balance-beam is caused, for the cup N being full of water, it overbalances M, and descends. The counterpoise P, being no longer restrained, descends by virtue of its weight and assumes the position it held at the commencement of the first period. This movement at the same time causes the closing of the valve B and the opening of A. This commences a new period of compression, and the movements of the different organs is repeated, as given above.

Fig. 3.

As soon as N is so nearly immersed as to allow M to overbalance it, the arm XY takes such a position that the tooth r is to the left of the stop, and this prevents any unseasonable movement of the counterpoise P during the period of compression.

It was remarked in the beginning that the valves A and B were double-seated, and that the two openings of each valve were unequal. This adjustment is necessary to avoid the escape of the water by B during compression, or by the valve A during the exhaust. To effect this the lower seat of the valve A presents a little more surface than the upper. In B the upper is the larger one.

The above description will suffice to convey an idea of the special advantages of this machine, as well as of its remarkable simplicity. It requires no superintendence, and the dimensions required are such as to adapt it to all the necessities of exploitation.

Fig. 4 shows an arrangement of compressors connected in a vertical series. The distances between them vary according to the tension required in the compressed air. The reservoir for the compressed air is preferably located on the surface, on account of its size.

The heating of the air during compression is easily controlled by a spray of water.

Mariotte's law enables us to determine the time necessary for each period of compression and exhaustion, and consequently the volume of compressed air at a given tension, which can be furnished by a machine of given size.

Let D = interior diameter of the compressor.

l = height of the compressor.

S = area of cross section $= \frac{\pi D^2}{4}$.

d = diameter of inlet and outlet valves.

s = effective area of these valves at the moment of equilibrium $= \frac{\pi d^2}{4}$

h = height of the water column.

y = a certain height attained by the water in the compressor during compression.

T = time necessary to produce equilibrium.

t = time necessary for outflow.

P = height of water column which balances atmospheric pressure $= 10.^m33$.

Then
$$y + \frac{Pl}{l-y} = h$$

whence
$$y = \frac{h+l}{2} \pm \sqrt{\frac{(h-l)^2}{2} + Ph} \quad (1)$$

This gives the value of y in terms of h.

Now, if v represent the velocity of the inflow of water during the first period, and dt the element of the time, we shall have:

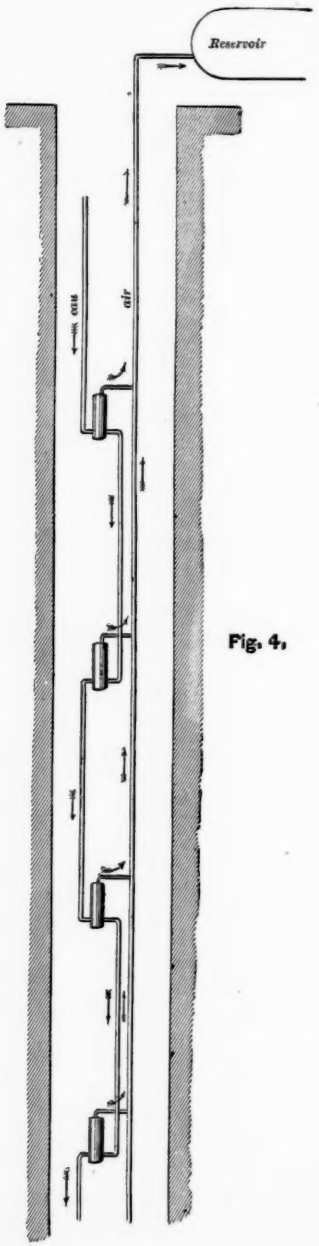


Fig. 4.

$$sv\,dt = S\,dy \quad \text{and} \quad v = \sqrt{2g\left(h - \frac{Pl}{l-y}\right)}$$

using the value of y for the height.

Substituting in the first of these equations the value of v, taken from the second, we have:

$$dt = \frac{S}{s\sqrt{2gh}} \times \frac{dy\sqrt{l-y}}{\sqrt{l-y-\frac{Pl}{h}}} \qquad \text{whence}$$

$$T = \frac{S}{s\sqrt{2gh}} \int_0^a \frac{dy\sqrt{l-y}}{\sqrt{l-y-\frac{Pl}{h}}} \qquad (2)$$

By substituting u for $\sqrt{l-y}$, integrating and replacing u by its value, we get

$$\int \frac{dy\sqrt{l-y}}{\sqrt{l-y-\frac{Pl}{h}}} = -\sqrt{(l-y)\left(l-y-\frac{Pl}{h}\right)} - \frac{Pl}{h}\log'\left(\sqrt{l-y} + \sqrt{l-y-\frac{Pl}{h}}\right)$$

which substituted in eq. 2, gives the time T necessary to establish equilibrium in the compressor.

The time necessary for the outflow is given by the equation

$$t = \frac{S\sqrt{2l}}{s\sqrt{g}} \qquad (3)$$

To apply the above equations let $h=30$ metres, and giving dimensions to the apparatus which the inventor considers proper, we may let

$l=2$ metres,
D=1.2 metres,
and $d=0.10$ "

from which we get

S=1.^{m}13097,
s=0.00785,

and the equations (1), (2) and (3) will give

$y=a=1.^m28$,
T=12.″430572,
$t=92''$.

A single compressor will furnish then, per hour a volume V of compressed air at a tension of 3 atmospheres.

$$V = \frac{3600\,S\,(l-a)}{T+t} = 28 \text{ cu. metres},$$

an amount which may be doubled, as the preceding calculations have been based upon single valves only.

We may calculate the coefficient of useful effect C.

Let W=total theoretical work of the motor,

W′=total theoretical work of the resistances,

n=No. of atmospheres pressure corresponding to h,

P=10.^{m}33 as before,

we shall have

$$C=\frac{W}{W'}=\frac{PV(1+lg'n)}{PVn}=\frac{1+lg'n}{n}$$

which gives for $n=3$ atm. C=0.699,
$n=4$ " C=0.596,
$n=5$ " C=0.521.

The theoretical useful effect is nearly 70 per cent., when the pressure is only 3 atmospheres, and amounts to 52 per cent. when the compression is pushed to 5 atmospheres. The real results of the apparatus already made are not known, but it seems reasonable to expect a near approach to these values, by reason of the insignificant character of the resistances.

THE INOXIDATION OF IRON, AND THE COATING OF METALS AND OTHER SURFACES WITH PLATINUM, BY THE PROCESSES OF MONS. DODÉ.

By L. M. STOFFEL, C. E.

From "Journal of the Society of Arts."

The origin of the patented processes, about to be described, for the inoxidation of iron, the enamelling of metals, and the platinum coating of metals, arose, incidentally, out of the researches in which M. Dodé had long been engaged, for the application of chloride of platinum to the silvering of glass, in a form that should supersede the deleterious mercurial processes in common use.

Although the title of the present paper contains reference to the platinising of glass and other substances, it is intended, on this occasion, solely to confine the description of M. Dodé's inventions to their application to metal surfaces. At some later period an opportunity may be afforded of treating, in another paper, the bearing of two of the processes concerned in the treatment of glass, whether in the form of sheets or tubes, or of blown or moulded objects, and also of ceramic ware.

The problem of the inoxidation of iron, or, in other words, of the permanent preservation of that most useful of metals from the attacks of rust, has long occupied attention. The possible utilization for this purpose of platinum—a metal possessing the qualities of being entirely unaffected by atmospheric changes—has not escaped research. Nevertheless, none of the attempts hitherto made in this direction can be said to have led to a practical result, or one applicable to manufacturing purposes. The two latest of these, namely, those of Professor Barff and Mr. Bower, depend upon the production of a superficial coating of magnetic oxide; and, however excellent in their way, can scarcely be termed ornamental. When any other color than bluish-grey is required, they are inapplicable, and the material has to be painted in the ordinary way.

Hitherto, the rendering of metallic objects impermeable to rust, has been partially accomplished by means of electro-plating—a lengthy, costly and in many cases inapplicable method. Iron, for instance, cannot be electro-silvered without an intermediate coating of copper. Moreover, cast iron articles placed in an acid bath, as a preparatory step to being subjected to galvanic action, have their fibre irretrievably deteriorated. The first action of the acids employed in the ordinary galvanic process is actually to form a coating of the objectionable oxide or rust upon the surface treated. On this the metal to be applied deposits

itself. But the layer of oxide beneath the outer covering of metal is never entirely got rid of. It is always liable to affect the outer surface of the object coated, as may be frequently observed in galvanized iron, and in all cases the coating of deposited metal has to be of a sufficient thickness to counteract the spontaneous oxidation primarily due to the acid used in the galvanic process.

It seems to have been reserved for M. Dodé, a French chemist of repute, whose family have for several generations actively devoted themselves to metallurgical research, to perfect and patent processes successfully solving the two-fold problem of the inoxidation of iron and the application of platinum to its surface in a practicable and inexpensive manner.

The first process, "inoxidation of iron," consists in coating, either by means of a bath or a brush, any objects in cast or wrought iron (freed from the damp they may contain) with a composition consisting of borate of lead, oxide of copper, and spirits of turpentine. This application soon dries on the surface of the iron, and the objects are then passed through a furnace, which is heated from 500° to 700° Fahr., according to the thickness of the articles under treatment, so as to bring them to a cherry heat when passing through the center of the furnace. At this point, the fusion of the metallic pigment takes place; it enters the pores of the iron, and becomes homogeneously adherent thereto; covering the objects with a dark color, not liable to change through atmospheric, gaseous, alkaline or other influences, nor to disintegrate from the surfaces to which it has been applied. When any considerable depth of inoxidation is desired, the object may be immersed in the composition for the time requisite to absorb a sufficient quantity thereof. Corrugated iron may be treated by means of the above described coating, which supersedes galvanizing, is of lesser cost, and is produceable in several hues of dark color. This first process wholly supersedes painting and varnishing, and metallic objects thus treated are rendered impervious to rust, and hence are of much greater durability. The cost of application is computed at an average of ¼d. per superficial square foot.

The second process, "enameling of metals," consists in a repetition of the coating operation, but with a pigment differing from that above described, and having for its object the production of a smooth polished surface, such as is obtained with thick enamels. This pigment, which is composed of borate of lead, litharge and essence of lavender, may be applied directly upon metal, and it renders iron also inoxidizable, although not to such a degree of perfection as when preceded by the first process. Its object is to supersede enamels, which it does most advantageously, with respect to cost and durability, while furnishing a smooth and even surface for receiving and effectually protecting the subsequent economical application of platinum or gold to articles thus treated. An extensive variety of colored enamels may be produced, separately or in combination. The cost of this process is computed at 1d. to 1½d. per square foot superficial.

The third process, "platinum coating of metals," is applicable to both of the inoxidating and the enameling processes, but with this difference of result:—In the first case the platinum yields the appearance of dull silver, and in the second it resembles this metal so highly burnished as to render any subsequent polishing wholly unnecessary. The dry chloride of platinum dissolved in ether, and held in solution by essential oils, is simply applied by means of a painter's brush or a bath, according to the ornamental effects desired, and by the simple aid of heat sufficient to cause the evaporation of the medium which holds the platinum in solution, a heat not exceeding 350 to 400° Fahr., the platinum becomes incorporated with the inoxidated surfaces. The result is, that a relatively infinitesimal portion of platinum suffices to coat a considerable surface; while this metal, being unaffected by atmospheric variations or by the products of combustion of gas, objects treated by M. Dodé's inventions are rendered unalterable by exposure, or by ordinary wear and tear. The cost of this last process varies from 1d. to 3d. per square foot superficial, according to the thickness of the metallic coating applied. When it is desired to produce a highly brilliant surface, two successive coats of the preparatory enameling are

given, and an increased quantity of the platinum solution is applied. Gold, similarly prepared, may be used in lieu of, or in combination with, platinum, at considerably less cost than when employed for electro or leaf gilding. In the case of platinizing or gilding objects of polished metal, the first coating may be entirely dispensed with. No burnishing is required in order to produce a bright surface with this process.

With reference to the various degrees of heat which are essential to the successful application of M. Dodé's process, it is necessary to remark that, as the metal objects subjected to treatment are heated and cooled gradually by special furnace arrangements, and as the maximum duration of exposure to the greatest heat does not exceed five or six minutes, no detrimental effect whatever can possibly ensue.

By M. Dodé's process, which substitute heat for galvanism, the use of acid is entirely dispensed with, and, there being thus no cause to encourage oxidation, no obstacle is offered to the instantaneous amalgamation of the original surface with the applied metal; a sufficient degree of heat only is required to cause the evaporation of the substances by which the latter are held in solution and fusion. The merit of the discovery lies in the method of preparing and holding the various metallic pigments in solution, and in directly applying them to the objects under treatment, with no other aid than such degrees of heat as do not affect the condition of the metals treated. Compared with electro-plating and galvanizing, these processes, by reason of their moderate cost and the facility of their application, present such advantageous features that a large field for operation is thereby opened.

In fact the field offered in the industrial world for the practical application of M. Dodé's inventions may fairly be described as boundless. There is hardly any limit to the application of the processes save the size of the furnace, and hence they can be applied with equal facility, and by common mechanical means, to a metal paper-weight or a pillar letter-box, to a door-knob or to a park-gate.

By the black or inoxidating process objects are rendered durable, by the enameling and the platinizing processes absolutely beautiful, and at the same time impervious to the effects of outdoor exposure. It is not too far perhaps, to look forward to the day when galvanized iron roofs and buildings, in their grey unsightliness, will be replaced by sheets of softly glittering metal, pleasantly refreshing, rather dazzling to the eye, when lamp-posts, converted into gleaming pillars of silver, or gold, or bronge, shall reflect the lustre of the flame they support, and when pillar letter-boxes, street orderly bins, and metal corner posts shall combine the useful with the attractive. Iron railings, too, around public monuments and building, such as the British Museum, instead of requiring continual coats of paint, or having their spikes periodically covered with gold leaf at a great expense, compared with the effect and durability obtained, may be advantageously treated by M. Dodé's invention; for he contends that by the substitution of gold for platinum as the outer coating in his process, he can produce the effect of gilding at one-twentieth of the cost where gold leaf is employed, and obtain at the same time an infinitely greater durability. Here is an opportunity for the City or Cathedral authorities to venture upon an experiment which deserves trying. The railings round St. Paul's Cathedral are to be redecorated, simultaneously with the improvement of the churchyard. Instead of adopting the present expensive method of gilding, why not coat them with M. Dodé's composition, at considerable saving in the cost?

In all cases cost is a most important feature of preservative operations, and it may be broadly stated, in reference to M. Dodé's method, that the cost of platinizing is about equal to that of applying three coats of paint, and about one-tenth of that of electro-plating with nickel. These comparisons have reference to Paris prices, which, as a usual rule, are not lower than English. A detailed account of the treatment of eight stoves, one of which is now exhibited to this meeting, is as follows:—

(*Detailed account on following page.*)

being 2 francs, or 1s. 8d. per stove. The French trade is quite willing to pay four times this rate, as to nickel-plate, a similar stove costs from 30 francs to 40

	Frs.
1 litre preparation (retail).....	3.75
First furnace operation.....	3.20
Reagents for platinizing.....	4.00
Second furnace operation.....	3.30
Manipulation, wear and tear, &c.	1.85
	16.10

francs; and the Val d'Osne Company, who are large manufacturers of these stoves, have expressed a highly favorable opinion of the results arrived at.

The preservation of iron ships from the action of salt water by means of M. Dodè's invention, is a problem as yet requiring further investigation. But so far as a ship's numerous fittings, now made in brass or galvanized iron, are concerned, there can be no doubt of the superior strength and durability of metal treated according to his patent, and there would be no comparison between the strength of galvanized and platinized iron-wire for standing rigging. The insulation and preservation of telegraph wires, and the preservation of the iron-work portions of railway rolling stock, also deserve attention.

M. Dodé may, at least, be congratulated upon having successfully solved a problem that has been for a long time occupying the attention of the iron trade, namely, the opening up of a fresh field for the employment of wrought and cast iron. Ordinary cast or wrought iron preserved and decorated at a trivial cost, according to his methods, will replace, to a considerable extent, copper, nickel, brass, and other costly metallic substances hitherto employed. Large foundries devoted to the production of ornamental metal work are likely to accord an unfeigned welcome to a discovery which will enable them to preserve their manufactures from rust, obviate all necessity for periodical polishing whilst the articles remain in stock, and also enhance their appearance and, consequently, their value.

Articles of common use, and ornamental productions of high class, can be advantageously subjected to M. Dodé's processes at very moderate cost; while the market value of all objects treated is considerably enhanced, not only through their highly ornamental appearance, but also by reason of their non-liability to corrosion.

In concluding this brief explanation of the various advantages presented by M. Dodé's discoveries in metallurgy, it is only necessary to call attention to the various specimens exhibited this evening, and to state that, M. Dodé being present, it will afford him much pleasure to explain any matters of detail, or to answer any questions bearing upon practical applications of his inventions.

STEEL MAKING IN INDIA.—The Government have instructed Mr. Walter Ness to proceed with the making of steel in the central Indian provinces with the Lohara and Pipalgaon iron ores, smelted with the Warora coal and the Khandalla limestone. An Indian Blue Book contains a summary by Mr. Ness of the full report which he left at the Indian Office before he again returned to India, detailing his experiments in this country with the materials we have specified. Mr. Ness's summary points out that, whilst by other methods only 30 per cent. of iron was obtainable from the ore charged, still by the modification, by Mr. Ireland, of Manchester, of Blair's patent iron sponge reducing furnace, of which he is part proprietor, the yield was 65 per cent. of iron sponge from the ore charged, the sponge containing fully 93 per cent. of metallic iron. As much as 6 tons of sponge had in this way been manufactured; and Mr. Ness reported in favor of a modification of such a furnace for use in India. Mr. Ness writes:—"I am not aware that any one capable of forming a correct notion of the working of this arrangement has seen it at work, excepting Mr. Snelus, of the Barrow Iron and Steel Works; and I have recently noticed in the *Engineer* that he testified, at the meeting of the Iron and Steel Institute held last March in London, to the rapid working of the arrangement, and the good result obtained." Varied trials, to ascertain the best arrangement for the melting of the sponge, culminated in the discovery made at the works at Annen of Messrs. Astowers, that this could be best done in the Bicheroux furnace, where the commonest fuel only is required to be used for the purpose; and it was ultimately resolved that this, or Dr. Siemen's gas-regenerative steel melting furnace, would be the most suitable for the purpose. A portion of the steel was made into bars suitable for engraving tools, and dies for mint purposes, and about 2 tons of sponge remained at the time of Mr. Ness's leaving England, which it was proposed to convert into steel shot or shell for armor-piercing purposes, the tenacity of the steel and its resistance on impact being exceptionally good. The Chief Commissioner of the Central Provinces, in his "Minute" to the annual progress report, says of Mr. Ness's experiments: "There appears to be every reason to hope that they may lead to the establishment of a very important local industry, and the development of the resources of the country."

A NEW AND GENERAL MOMENT OF INERTIA FORMULA.

By J. WOODBRIDGE DAVIS, C.E.

Written for VAN NOSTRAND'S MAGAZINE.

THE following formula expresses one component of the moment of inertia of the mass, whose density is unity, contained in each of certain shapes, referred to an axis situated at the first end of the shape.

$$\tfrac{3}{10}D^2V+\tfrac{1}{30}D^3(3B-2A) \qquad (1)$$

The symbols are the same used in the center of gravity formula. [See June No. of this Magazine.] The space is considered to be described by a plane generatrix, which remains parallel to one plane, while it moves in direction perpendicular to it. If the shape be a surface, the generatrix is a line. A is the magnitude of generatrix at initial position, B its magnitude at final position, D the distance between these positions, or the length of the space, and V is the amount of space described. In this paper the axis of gyration, whatever its situation, is considered to be parallel to the plane of generatrix.

The component of inertia is that which acts in direction perpendicular to the path of generatrix. This component is equal to the moment of inertia of the whole mass, on the supposition that the mass which fills the space described by the generatrix in each instant, is concentrated upon the same single line that indicates the path of that generatrix.

This supposition may often be made with practical accuracy.

If formula (1) be applicable to the shape in direction normal to last, the remaining component can be obtained in same manner. The sum of these two is the entire moment of inertia of the mass, whose specific gravity is unity, and which fills the shape in question. If the heaviness of the material be γ, γ should enter formula (1) as a factor.

The generatrix may be, instead of a plane, a circular cylindric surface, or a plane circular circumference, which proceeds concentrically from the axis. For this case, formula (1), if it apply, indicates the entire moment of inertia, because every point of generatrix is at same time equally distant from axis.

The range of this formula's applicability can be determined by solution of the following equation with respect to n, the space discussed being

$$y=Kx^n, \qquad (2)$$

where y is variable area of generatrix, x is its corresponding distance from initial position, and K and n are constants. [See introduction to article on *The Prismoidal Formula* in May No. of this Magazine.] The equation referred to is

$$\tfrac{3}{10}D^3\frac{KD^{n+1}}{n+1}+\tfrac{1}{30}D^3[\,3KD^n-2K(0)^n\,]-\int_0^D Kx^{n+2}dx=0. \qquad (3)$$

When n is zero, this equation is true. For all other values, it reduces to

$$\frac{3}{10(n+1)}+\frac{1}{10}-\frac{1}{n+3}=0. \qquad (4)$$

From this

$$n=\tfrac{3}{2}\pm\tfrac{1}{2}=2 \text{ or } 1.$$

Here it is seen that the formula applies when the generatrix of space varies as ax^0, bx or cx^2. Consider three spaces between same limits, which vary each as a different one of these three functions of the path. Let A_1, B_1, V_1, belong to one of these spaces, A_2, B_2, V_2, and A_3, B_3, V_3, to the others. Then,

$$A=A_1+A_2+A_3, \quad B=B_1+B_2+B_3,$$
$$V=V_1+V_2+V_3,$$

where A, B, V, are the areas of ends, and the volume, of combined space. The combined moment of inertia is

$$\left.\begin{aligned}&\tfrac{3}{10}D^2V_1+\tfrac{1}{30}D^3(3B_1-2A_1)\\&\tfrac{3}{10}D^2V_2+\tfrac{1}{10}D^3(3B_2-2A_2)\\&\tfrac{3}{10}D^2V_3+\tfrac{1}{30}D^3(3B_3-2A_3)\end{aligned}\right\}$$
$$=\tfrac{3}{10}D^2V+\tfrac{1}{30}D^3(3B-2A). \qquad (1)$$

Hence the moment of inertia formula applies between any limits to all spaces represented by the equation

$$y=a+bx+cx^2. \qquad (5)$$

The formula applies to no other spaces except between particular limits which

occur but once in an infinite number of cases, as has been already demonstrated of the center of gravity formula.

Formula (1), though exceedingly simple, possesses, as shown by eq. (5), as great an extent of applicability as the center of gravity formula, and, practically, as the prismoidal formula. Consequently, it applies to all the practical shapes mentioned in connection with those formulæ. Eq. (5) is, as with them, the criterion.

Moreover, this formula for moment of inertia, has the same variety of uses to the writer of theoretical mechanics and to the practical engineer, as has been fully discussed in connection with the centre of gravity formula.

The moment of inertia formula has one disadvantage not shared by the prismoidal and center of gravity formulæ, which is that it must always be applied in two directions to spaces of three dimensions. This reduces the number of shapes to which formula (1) applies for both components, or for the entire moment of inertia, since a shape may in one direction be generated according to the law expressed in eq. (5), but be described in a direction normal to this, according to a very different law. The prismoidal formula requires to be applied in one direction only. To all shapes which have an axis of symmetry the center of gravity formula requires but a single application. Often, of shapes which possess no axis of symmetry, the statical moment in but one direction is sought. But, that a complete result may be obtained, the moment of inertia formula must be applied in both ways.

Notwithstanding this, it will be seen that, for all practical cases, formula (1) applies exactly in both directions.

Let us examine a few examples in order to become familiar with the method of applying the moment of inertia formula.

The moment of inertia of a bar of uniform thickness, but whose length, l, is comparatively great, is, referred to an axis at one end, perpendicular to direction of length,

$$\tfrac{3}{10}l^2\mathrm{V}+\tfrac{1}{30}l^2\mathrm{A}=\tfrac{1}{3}l^2\mathrm{V}.$$

If the axis be passed through a point of bar, distant l_1 from one end, and l_2 from the other, the moment of inertia is

$$\tfrac{1}{3}(l_1^2\mathrm{V}_1+l_2^2\mathrm{V}_2)=\tfrac{1}{3}\mathrm{A}(l_1^3+l_2^3)$$

To determine the square of the radius of gyration, with respect to same axis, divide the moment of inertia by V. This is evidently independent of the density. For the bar it is in first case $\frac{1}{3}l^2$, and in second case

$$\frac{l_1^3+l_2^3}{3(l_1+l_2)}=\tfrac{1}{3}(l_1^2-l_1l_2+l_2^2).$$

If the axis be beyond either end of bar, the last expression is true when the sign of middle term is made plus.

Let it be required to determine the moment of inertia of a circular disc referred to a normal axis through its center.

The generatrix is a varying circumference. Because it varies as ax, formula (1) applies.

$$\therefore \text{ m. of i.}=\tfrac{3}{10}r^2.\pi r^2+\tfrac{1}{30}r^3[3(2\pi r)-0]$$
$$=\tfrac{1}{2}\pi r^4.$$
$$\text{rad.}^2 \text{ of gyr.}=\tfrac{1}{2}\pi r^4\div\pi r^2=\tfrac{1}{2}r^2.$$

One component of this moment of inertia is, obviously, on account of the symmetry of the shape,

$$\tfrac{1}{4}\pi r^4.$$

This is, consequently, the moment of inertia of the disc when the axis is a diameter.

From the foregoing is obtained for circular ring

$$\text{m. of i.}=\tfrac{1}{2}\pi(r_2^4-r_1^4),$$
$$\text{rad.}^2 \text{ of gyr.}=\tfrac{1}{2}(r_2^2+r_1^2).$$

Referred to a diametral axis, the m. of i. and rad.^{2} of gyr. of same figure, are one-half so great.

One component of the m. of i. of hemisphere, referred to a diameter of section, as axis, is

$$\tfrac{3}{10}r^3.\tfrac{2}{3}\pi r^3-\tfrac{1}{30}r^3.2\pi r^3=\tfrac{2}{15}\pi r^5.$$

Hence this component for entire sphere is $\frac{4}{15}\pi r^5$. But the other component is equal. Therefore, the entire m. of i. of sphere, referred to axis through center, is

$$\tfrac{8}{15}\pi r^5;$$

and $$\text{rad.}^2 \text{ of gyr.}=\tfrac{2}{5}r^2.$$

If the axis be a line tangent to the sphere, one component of m. of i. is

$$\tfrac{3}{10}\mathrm{D}^2.\tfrac{4}{3}\pi r^3.$$

Formula (1) applied in direction at right angles to this, gives, as before,

$\frac{4}{15}\pi r^5$.

$\therefore$ m. of i. $= \frac{3}{10}.4r^2.\frac{4}{3}\pi r^3 + \frac{4}{15}\pi r^5 = \frac{8}{15}\pi r^5$,

and rad.^{2} of gyr. $= \frac{7}{9}r^2$.

When the axis is anywhere between limits of space, divide latter into two portions, apply formula (1) to each and compound the moments of inertia, as was done in case of bar and sphere. When the axis is beyond limits, produce the shape, if possible, to the axis, find m. of i. between axis and last limit, then find m. of i. between axis and first limit, and substract the latter from the former, as was done in case of circular ring.

Sometimes the shape cannot be produced to the axis, as in the case where m. of i. of sphere is required, referred to an axis which does not touch it. For such cases another formula must be constructed, which represents the amount to be added to that of formula (1) in order that the sum shall be the entire component of the m. of i. referred to the axis under consideration.

Let d_1 be the distance of the axis beyond first end, d_2, the distance of the center of gravity of mass from first end, measured in direction perpendicular to plane of generatrix, and M, the corresponding component of the m. of i. of the mass referred to an axis through center of gravity. By the principles of mechanics the component of m. of i. referred to first axis is

$$(d_1^2 + 2d_1d_2 + d_2^2)\mathrm{V} + \mathrm{M} \qquad (6)$$

But formula (1) is, by same principles, equivalent with

$$d_2^2\mathrm{V} + \mathrm{M}. \qquad (7)$$

Therefore, to this must be added, in order to obtain (6),

$$d_1(d_1 + 2d_2)\mathrm{V}. \qquad (8)$$

According to formula (1) in center of gravity article in June No. of this magzine,

$$d_2 = \tfrac{1}{2}\mathrm{D} + \frac{(\mathrm{B}-\mathrm{A})\mathrm{D}^2}{12\mathrm{V}} \qquad (9)$$

Hence, expression (8) is equal to

$$d_1[(d_1 + \mathrm{D})\mathrm{V} + \tfrac{1}{6}\mathrm{D}^2(\mathrm{B}-\mathrm{A})]. \qquad (10)$$

The sum of expressions (1), (10), is one component of the m. of i. referred to any axis parallel to plane of generatrix. It is

$$\left.\begin{array}{l} d_1[(d_1 + \mathrm{D})\mathrm{V} + \tfrac{1}{6}\mathrm{D}^2(\mathrm{B}-\mathrm{A})] \\ + \frac{3}{10}\mathrm{D}^2\mathrm{V} + \frac{1}{30}\mathrm{D}^2(3\mathrm{B}-2\mathrm{A}) \end{array}\right\} \qquad (11)$$

The same formula may be used to determine the other component. The sum of these is the total m. of i. of the mass.

In cases where the center of gravity is in first end, as in example of the circular disc, and one example of the sphere, $d_2 = 0$, and expressions (8), (10) reduce to

$$d_1^2\mathrm{V}. \qquad (12)$$

In these cases, formula (1) applied once or twice, gives the entire m. of i. referred to axis through center of gravity; and formula (12) applied once, gives the amount to be added to this to compose the entire m. of i. referred to any axis.

Let it be required to determine the m. of i. of a hemisphere, whose radius is r, situate at the extremity of a rod, whose length is d_1, the axis being at other end, and the plane face of figure being directed toward this.

Referred to a diametral axis in plane face, the whole m. of i. is, as before shown, $\frac{4}{15}\pi r^5$. Add to this formula (10). Then,

$$\text{m. of i.} = \tfrac{4}{15}\pi r^5 + d_1[(d_1 + r)\tfrac{2}{3}\pi r^3 - \tfrac{1}{6}\pi r^4]$$
$$= \pi r^5[\tfrac{4}{15}r^3 + d_1(\tfrac{2}{3}d_1 + \tfrac{1}{2}r)].$$

$$\text{rad.}^2 \text{ of gyr.} = \tfrac{8}{9}r^2 + d_1(d_1 + \tfrac{3}{4}r).$$

The m. of i. of a rectangular prism, referred to an axis coincident with one edge, is, when l, b, are lengths of remaining two edges, and t, the length of first edge, which form one solid angle,

$$\left.\begin{array}{l} \frac{3}{10}l^2.btl + \frac{1}{30}l^2.bt \\ + \frac{3}{10}b^2.btl + \frac{1}{30}b^2.tl \end{array}\right\} = \tfrac{1}{3}btl(l^2 + b^2).$$

The m. of i. referred to a parallel axis, distant d_1 in direction of edge l, and d' in direction of edge b, is greater by

$$d_1(d_1 + l)btl + d'(d' + b)btl.$$

rad.^{2} of

$$\text{gyr.} = \tfrac{1}{3}(l^2 + b^2) + d_1(d_1 + l) + d'(d' + b).$$

One component of the m. of i. of a solid cylinder, referred to an axis at first end, intersecting axis of cylinder perpendicularly, is, by formula (1),

$$\tfrac{3}{10}\mathrm{D}.^2\mathrm{D}\pi r^2 + \tfrac{1}{30}\mathrm{D}.^2\pi r^2 = \tfrac{1}{8}\mathrm{D}^2\pi r.^2$$

The other component is the m. of i. of circular disc referred to diametral axis, multiplied by D. It is, accordingly, $\frac{1}{4}\pi r^4\mathrm{D}$.

$$\therefore \quad \text{m. of i.} = \pi r^2\mathrm{D}(\tfrac{1}{8}\mathrm{D}^2 + \tfrac{1}{4}r^2).$$

The m. of i. of same mass referred to a parallel axis distant d_1 in direction of axis of cylinder, and distant d' from this axis, is greater by

$$(d_1(d_1+D)+d'^2)\pi r^2 D.$$

$$\therefore \text{ rad.}^2 \text{ of } gyr. = \tfrac{1}{3}D^2+\tfrac{1}{4}r^2+d_1(d_1+D)+d'^2$$

The foregoing examples comprise all that are proposed in ordinary manuals: moreover, the results in several cases are more general than it is usual to present them. In every instance the formula applies exactly and very simply, removing the necessity for a special demonstration for every shape. It applies exactly to numerous other figures which occasionly rise to notice. The shapes to which it does not apply in both directions, as the paraboloid, are rare in practice. Even to these it applies with a very close approximation to the truth, and an immeuse saving of the labor that would be necessary to find the amount of inertia correctly by the method of calculus. So it appears that the disadvantage of the moment of inertia formula, as compared with the prismoidal and center of gravity formulæ, is rather theoretical than practical. A few more examples will be solved as briefly as possible.

The altitude of a right cone is h. The radius of its base is r. Required its m. of i. referred to its geometric axis.

The generatrix is a cylindric surface moving concentrically from axis. At distance x, its circumferential dimension is $2\pi x$; and its width is y, which we know to be a function of x involving the zero and first powers of latter variable. Hence formula (1) applies; and, since end magnitudes of generatrix are zero,

$$\text{m. of i.} = \tfrac{3}{10}r.^2\tfrac{1}{3}\pi r^2 h. \qquad (13)$$

Frusta of such cones occur in machinery quite frequently. For each the m. of i. is the difference between those of two cones. If r_1 be radius of smaller base, and h_1 its distance from vertex, and r_2, h_2, be corresponding values for other base,

$$\text{m. of i.} = \tfrac{1}{10}\pi(h_2 r_2^4 - h_2 r_1^4) = \tfrac{1}{10}\pi a (r_2^5 - r_1^5).$$

The altitude of a right square pyramid is h. Each side of its base is s. Required its m. of i. referred to its geometric axis.

Bisect pyramid by a plane through axis, perpendicular to a pair of opposite faces. The generatrix of one half is a trapezoid, which changes from a triangle at axis to a line at opposite edge. Formlua (1) applies, evidently. If, then, this formula be applied in four directions, at right angles, from the axis, both components of the m. of i. of every point will be included in the result.

$$\therefore \text{ m. of i.} = 4(\tfrac{3}{10}\cdot\tfrac{1}{4}s^2\cdot\tfrac{1}{6}hs^2 - \tfrac{1}{30}\cdot\tfrac{1}{8}s^3\cdot hs) = \tfrac{1}{30}hs^4,$$

$$\text{and} \qquad \text{rad}^2\text{. of gyr.} = \tfrac{1}{10}s^2.$$

The m. of i. of the cone, referred to an axis through vertex, perpendicular to geometric axis, is required.

One component is

$$\tfrac{3}{10}h.^2\,\tfrac{1}{3}h\pi r^2 + \tfrac{1}{30}h.^3 3\pi r^2 = \tfrac{1}{3}h^3\pi r^2.$$

The other is one half of (13), because the m. of i. of each elementary circle is now referred to a diametral axis.

$$\therefore \text{ m. of i.} = h\pi r^2\left(\frac{h^2}{5}+\frac{r^2}{20}\right).$$

To obtain m. of i. referred to a parallel axis through center of gravity of cone, distant $\frac{3}{4}$h, subtract

$$\tfrac{9}{10}h.^2\,\tfrac{1}{3}h\pi r^2.$$

By similar process, the moments of inertia of the right, rectangular pyramid, the hollow cylinder and many other shapes, may be determined with respect to any axis, parallel with plane of generatrix.

We have in mechanics the rule:

The distance from the center of pressure on a submerged plane surface to the intersection of that plane with surface of fluid, is equal to the moment of inertia of the plane, referred to the intersection, divided by the statical moment of the plane referred to same line. Hence, expression (11), of this paper, divided by expression (16) of center of gravity article in June number of this magazine, represents this distance. The formula is

$$2d_1 + \frac{\frac{1}{10}D^2[3V+D(B-\frac{2}{3}A)]-d_1^2 V}{(d_1+\frac{1}{2}D)V+\frac{1}{12}D^2(B-A)} \qquad (14)$$

This applies to all plane figures represented by eq. (5), when the axis of Y is parallel with the intersection. But, as already remarked, we rarely have to deal with submerged shapes other than those represented by

$$y = a + bx;$$

and the simpler formula, (15), p. 471, June No., applies to these.

Each component of the m. of i., refer-

red to an axis through center of gravity of mass, is represented by

$$\tfrac{1}{2^4_0}D^2[V+\tfrac{1}{3}D(B+A)]-\frac{D^4(B-A)^2}{144\,V}. \quad (15)$$

The sum of these is the m. of i. referred to same axis. If d_1 be the distance, in any direction, to a second parallel axis, the m. of i. referred to latter, is greater by expression (12).

Formula (15) is rarely preferable to the other formulæ of this paper.

One of the most important applications of m. of i. formulæ, is to the determination of the amount of resistance to rupture by bending, possessed by beams, since one factor of this resistance is the same function of the dimensions, shape and position of the cross-section with regard to the neutral axis, as that which represents the m, of i. of the figure referred to same line. The computation of this quantity is, even for simple shapes, tedious; for complex figures it is very laborious. From formula (1) we may devise a rule appropriate to these cases in the following manner:

Let A, B, C, D, etc., be points anywhere situate in a plane; and let a', b', c', etc., be their abscissæ, and a, b, c, etc., their ordinates. Conceive the points to be connected in alphabetical order by a broken line, commencing and ending at A. We now have a polygon composed of a series of positive and negative trapezoids lying consecutive with their bases all on the axis of abscissæ. Apply formula (11) to the trapezoid AB. After reduction, its m. of i. is represented by

$$\tfrac{1}{12}a'(b'-a')[2a'(a-b)+4b'(a+2b)] + \tfrac{1}{12}(b'-a')^3(a+3b). \quad (16)$$

If the trapezoid be negative, $a'>b'$, [See article on land surveying in April number of this magazine] and the factors $(b'-a')$, $(b'-a')^3$, are negative; and, consequently, the m. of i. is negative. Hence, the algebraic sum of the moments of inertia of all the trapezoids, as represented for each by formula (16), is the m. of i. of the polygon.

The m. of i. of the trapezoid BC is

$$\tfrac{1}{12}b'(c'-b')[2b'(b-c)+4c'(b+2c)] + \tfrac{1}{12}(c'-b')^3(b+3c). \quad (16a)$$

The symbol b occurs in the formulæ for trapezoids AB, BC only. Selecting from these the terms in which b enters as a factor, and joining them, we obtain

$$\tfrac{1}{12}b(c'-a')(a'^2+a'b'+b'^2+a'c' + b'c'+c'^2). \quad (17)$$

Evidently, the formula for every other ordidate is the same; and the sum of these is the m. of i. of polygon.

(17) may be transformed into

$$\tfrac{1}{12}\begin{cases} b(c'-a')(a'+b'+c')(a'+c') & (18a) \\ +b(c'-a')(b'^2-a'c') & (18b) \end{cases}$$

Here it is seen that the first three factors of (18a) are the three literal factors of the corresponding term of the statical moment, and that the first two factors of (18b) are the two literal factors of the corresponding term of the area. [See Rule B, p. 293, April No. of this Magazine, and formula (32), p. 472e, June No.] The advantage of formula (18) appears from what follows.

The required quantity is the m. of i. of the cross-section of beam, referred to a line in its own plane coincident with the neutral axis. To find position of latter, we must ascertain one co-ordinate of the center of gravity. But this depends upon the statical moment and the area. Therefore, the three necessary elements of the solution are the determinations of the area, statical moment and the moment of inertia. Now, in formula (18) we have not only the simplest m. of i. formula for the general polygon, but from the labor it represents we derive at same time the area and statical moment of polygon. Compare with this the following methods for complex figures.

A common process is to divide the cross-section into equally long trapezoids, and apply Simpson's rule three separate times to the elementary quantities of the m. of i., the statical moment and the area. The disadvantages of this are that more ordinates must be measured than are necessary, and that the three elements of the solution require independent operations.

Another method, exceedingly crude and laborious, as any one will discover who attempts to use it, is thus described by Rankine on page 253 of *Civil Engineering:*

"In finding the value of the moment of inertia I of cross-sections of complex figure, the following rules are useful:

"If a complex cross-section is made up of a number of simple figures, conceive the center of gravity of each of those

figures to be traversed by a neutral axis parallel to the neutral axis of the whole section. Find the moment of inertia of each of the component figures relatively to its own neutral axis; multiply its area by the square of the distance between its own neutral axis and the neutral axis of the whole section; and add together all the results so found, for the moment of inertia of the whole section.

* * * * * *

"When the figure of the cross-section can be made by *taking away* one simpler figure from another, so that the center of gravity of the whole figure is found by *subtraction* (as in p. 154), both the area and the moment of inertia of the subtracted figure are to be considered as negative."

These rules suggest another advantage of the method represented in formula (18), which is, that no care need be taken to separate the negative areas and moments from the positive. The rule effects the algebraic summation without mistake or special superintendence. Another advantage of this rule, apparently trifling but really important, is that it has but one numerical factor for the whole polygon, while the other rules mentioned require the constant use of the factors, $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{1}{6}$, $\frac{1}{12}$.

Formula (18) is designed for complex figures only, such as the cross-section of a track-rail; but, as it is perfectly general, it may be used for any right-line shape. When applied to shapes composed of rectangles, as the T and double T-shaped cross-sections, it cannot so well compete with ordinary rules, because the latter need not be applied to the trapezoids, such as AB, CD, GH, Fig. 1, since it is known at once that these are zero, while formula (18) must be applied as often to Fig. 1 as to Fig. 2. But, wherever trapezoids occur, as in Figs. 1, 2, and as is very common, formula (18), notwithstanding the disadvantage just mentioned, is the shortest rule. Moreover, girders are not usually manufactured with sharp angles at D and E; so that we shall commonly have the side CD a reversed curve tangent to the lines BC, DE. For instance, the girder, of which Fig. 1 is the type, is represented, as actually measured, in Fig. 3 (where the scale is one-half and the web rectangle is omitted); and as such it should be calculated, if an exact result be required. This was reduced to the shape of Fig. 1, in order that the result of the computation might be the more easily tested by ordinary methods. Had we applied formula (18) to Fig. 2 instead, we should have incurred no more labor to find the m. of i.; but, by the ordinary rule, the work would have been nearly tripled. It is desirable to have the first example such that the result of the operation can be easily tested.

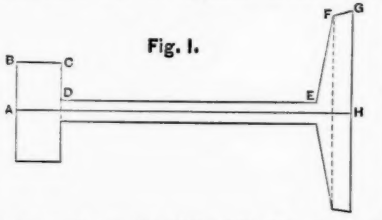


Fig. 1.

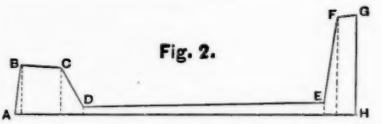


Fig. 2.

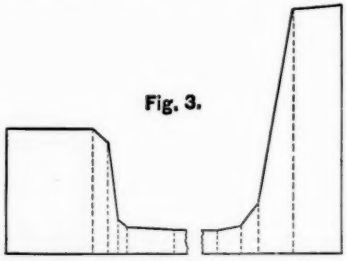


Fig. 3.

It is unnecessary to apply formula (18) to each vertex of figure. Draw the axial line AH, Fig. 1, and consider the polygon on one side. The entire ordinates, instead of the half ordinates, may, however, be used. The result is, then, the entire m. of i. When treating irregular shapes, whether symmetrical or not, solid or hollow, which are mensurated by having breadths taken at intervals, regard these ordinates as if erected from one straight line, the axis of abscissae.

The co-ordinates of the vertices of Fig. 1 are recorded in the table below next to the letters indicating those vertices. The symbols of formula (18) are used at the heads of the columns. Thus, column

headed b', contains the abscissæ; under b are the ordinates. Each number under $(c'-a')$ is derived from the subtraction of number on the line above, under b', from that on line below in same column. The numbers below $(a'+b'+c')$ are each the sum of the numbers in column of abscissæ, which occur on the same line and the adjoining lines above and below. The factors $(a'+c')$, $(b'^2-a'c')$ are also derived, in manner indicated, from the abscissæ. The factors $(b'^2-a'c')$ must be used with area terms. From twice the logarithm of the statical moment subtract the logarithm of the area. The result is logarithm of quantity which we must subtract from m. of i. as previously found, in order to reduce this to the m. of i. referred to neutral axis.

The work has been carried out to the

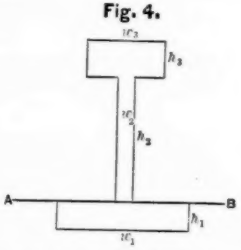
Co-ordinates.			Double Area.	Sextuple Statical Moment.	Duodecuple Moment of Inertia.	
	b'	b	$(c'-a')$	$(a'+b'+c')$	$(a'+c')$	$(b'^2-a'c')$ use with area terms
A	0	0				
B	0	3.	$\times 1.3=3.9$	$\times 1.3=5.07$	$\times 1.3=6.591$	$0=0$
C	1.3	3.	$\times 1.3=3.9$	$\times 2.6=10.14$	$\times 1.3=13.182$	$1.69=6.591$
D	1.3	0.6	$\times 7.7=4.62$	$\times 11.6=53.592$	$\times 10.3=551.9976$	$-10.01=-46.2462$
E	9.	0.6	$\times 8.1=4.86$	$\times 19.7=95.742$	$\times 10.7=1024.4394$	$68.78=334.2708$
F	9.4	5.9	$\times 1.0=5.9$	$\times 28.4=167.56$	$\times 19.0=3183.64$	$-1.64=-9.676$
G	10.	6.	$\times 0.6=3.6$	$\times 29.4=105.84$	$\times 19.4=2053.296$	$6.=21.6$
H	10.	0				
			$2)\overline{26.78}$	$6)\overline{437.944}$	$\overline{6833.1460}$	$\overline{306.5396}$
			$\overline{13.39}$	$\overline{72.991}$	306.5396	
					$12)\overline{7139.6856}$	
					$\overline{594.9738}$	
					-397.885	
					$\overline{197.0888}$=m. of i.	

2 log. 72.991= 3.726538
− log. 13.39 = −1.126781
2.599757=log. 397.885

last decimal place. This is not necessary in practice. This example shows exactly the amount of work requisite for calculation of m. of i. of Fig. 2, even were GH also inclined.

All the formulæ given in books for special plane shapes, not bounded by curves, can be deduced from formula (18), which thus obviates the necessity for special demonstrations. It is, moreover, already in simplest form for all polygons, except those composed of rectangles.

Fig. 4.



Following the same plan, we may construct a systematic formula for shapes composed of series of rectangles, which will be found simpler than the formulæ already in engineering treatises. The common case is the series of three rectangles: we shall confine our attention to this. Let the first axis be taken [Regard Fig. 4] coincident with the common side of two rectangles. The three following expressions for area, statical moment and m. of i., of whole figure, are easily derived.

$$A=h_1w_1+h_2w_2+h_3w_3=A_1+A_2+A_3, \quad (19a)$$

$$S'=\tfrac{1}{2}[-h_1A_1+h_2A_2+(2h_2+h_3)A_3] =\tfrac{1}{2}(S_1+S_2+S_3)=\tfrac{1}{2}S, \quad (19b)$$

$$M'=\tfrac{1}{3}[-h_1S_1+h_2S_2+(h_2+h_3)S_2+h_2^2A_3] =\tfrac{1}{3}(M_1+M_2+M_3)=\tfrac{1}{3}M. \quad (19c)$$

Hence comes the following scheme for a table of calculations:

$$\begin{array}{l|l|l|l|l|l|l} w_1 & h_1 & A_1 & \times -h_1 & =S_1 & \times -h_1 & =M_1 \\ w_2 & h_2 & A_2 & \times h_2 & =S_2 & \times h_2 & =M_2 \\ w_3 & h_3 & A_3 & \times(2h_2+h_3) & =S_3 & \times(h_2+h_3)) & \\ & & & & +h_2^2A_3 & & \} =M_3 \\ & & \overline{A} & & \overline{S} & & \overline{M} \end{array} \quad (20)$$

$$\text{m. of i.}=\tfrac{1}{3}M-\frac{(\frac{1}{2}S)^2}{A}$$

S_1 is always negative, and is the only negative quantity. The axis AB is more

conveniently placed next to the larger flange, as in diagram. This makes the quantity S smaller. The symbol, m. of i., means the m. of i. referred to neutral axis.

Formula (20) is, of course, independent of dimensions. w_2 may be greater than flange-widths, as in cross-shaped sections.

For T-shaped sections, simply omit the third, and most difficult, line of formula (20); because, now, in formula (19), h_3, w_3, A_3, S_3, M_3, are all zero.

It is already known that the neutral axis of a double T cross-section whose flange areas are equal and similar, bisects the web. Let w_2, h_2, be the width and height of half the web; and let w_3, h_3, be the width and height of one flange. Referred to neutral axis of whole cross-section, the m. of i. of one half is represented by formula (20), when the first line is omitted, that is, when all the symbols with figure one subjacent are zero. Multiply result by 2 to obtain entire m. of i.

To determine the m. of i. of a polygon with respect to any axis normal to its plane, pass through its foot a pair of rectangular axes, and determine by formula (18) the m. of i. referred to each of these. The sum is the required m. of i. One of these axes can always be passed through a vertex. The statical moment and area are not required in the solution.

To determine the m. of i. referred to normal axis through center of gravity, assume an axis in plane of polygon, passing through two vertices, and another which intersects this perpendicularly at one of these vertices. By formula (18), as illustrated in the example of girder cross-section, is obtained the m. of i. with respect to each of a pair of rectangular axes passing through center of gravity. The sum is the m. of i. required.

Since formula (18) is perfectly general, it applies to polygons which have negative portions, as represented in Fig. 4, p. 293, April No. of this Magazine. So, also, does the center of gravity formula for polygons. Such polygons are met with in practice.

The m. of i. of any polygon referred to any line in space, is equal to the m. of i. of projection of that polygon on plane normal to line, multiplied by the cosecant of the angle which the line makes with the plane of polygon.

From the foregoing applications of formula (18) can be found the m. of i. of any prism or pyramid, right or oblique, with respect to any axis whatever.

The prismoidal formula, the center of gravity formula, and the moment of inertia formula are similar in so much as that they are co-extensive in practical application. For all, the criterion is the quadratic equation. Though the first rule applies to shapes represented by the cubic equation, the additional shapes are very rarely met with. Many shapes have been described in connection with each formula, which to avoid repetition we have not mentioned when discussing the other two. Thus, the prismoidal formula applies to the circle, sphere and right cone, when the generatrices are, respectively, a varying circular circumference, a spherical surface and a circular cylindric surface, all concentric; and the other two formulæ apply to all the shapes, for which eq. (20), of article on prismoidal formula, is criterion, when q, the coefficient of x^3, in that expression is made zero. The center of gravity formula cannot, on account of the nature of the quantity it represents, be applied to spaces described by concentric generatrices; but it can properly be applied to these when the path is considered to be the distance passed through in one direction by the center of magnitude of generatrix.

Center of gravity and moment of inertia formulæ of wider application, but depending upon the magnitudes of more cross-sections, can be constructed, by methods analogous to those used to obtain rules, more general than the prismoidal, for magnitudes. By such a process the moment of inertia formula was constructed. It was not discovered. The method of procedure was as follows:

The formula was required to apply between any limits to all the spaces represented by the quadratic equation

$$y = a + bx + cx^2. \qquad (5)$$

Between limits 0 and D,

$$\text{rad.}^2 \text{ of gyr.} = \frac{\frac{1}{3}aD^3 + \frac{1}{4}bD^4 + \frac{1}{5}cD^5}{aD + \frac{1}{2}bD^2 + \frac{1}{3}cD^3}; \qquad (21)$$

and the end areas are

$$A=a,\ B=a+bD+cD^2. \qquad (22)$$

The division indicated in (21) performed, there is obtained

$$xD^2+\frac{(\frac{1}{6}-x)aD^3+(\frac{1}{4}-\frac{1}{2}x)bD^4+(\frac{1}{6}-\frac{1}{3}x)cD^5}{aD+\frac{1}{2}bD^2+\frac{1}{3}cD^3}. \qquad (23)$$

The denominator may be represented by V. That the numerator may be expressed in terms of A and B, the numerical coefficients, $(\frac{1}{4}-\frac{1}{2}x)$ and $(\frac{1}{6}-\frac{1}{3}x)$, must be equal, as shown by (22).

$$\therefore\ \tfrac{1}{4}-\tfrac{1}{2}x=\tfrac{1}{6}-\tfrac{1}{3}x;\ \text{whence } x=\tfrac{3}{10}$$

By substitution and reduction, formula (23) becomes

$$\tfrac{3}{10}D^2+\frac{D^2(3B-2A)}{30V};$$

whence formula (1). For a cubic equation, two unknown quantities must be employed, and so on.

The center of gravity formula, which suggested the other, is the result of a direct attempt to obtain a correction term for the assumption that the center of gravity of an earthwork solid is in its mid-section. The writer was surprised to find that the intricate expression which resulted could be reduced to the second term of the center of gravity formula, and still more so to discover that the whole formula was applicable to numerous common shapes. The method of procedure in this case is published in Van Nostrand's Magazine for July, 1877.

Undoubtedly, many other formulæ can be simplified in the same way, that is, by separation into an approximate and a correction term. The prismoidal formula itself can, for many shapes, be much simplified by this transformation. Such a form of the prismoidal rule has been used in certain calculations. Formula (2), or rule A, of article on *Land Surveying*, in April No. of this Magazine, was found in this way. It was desirable to represent approximately by a single term the content of a series of trapezoids or solids, for a reason mentioned in first paragraph on page 297 of that article. The correction became represented by a term for each intermediate ordinate. The correction terms in all four cases just noted, are each the difference between two similar quantities, and are, consequently, very easy, and may be zero. and often nearly zero.

ERRATA.—The formula near foot of p. 472*c*, left column, in article on *Center of Gravity* in June No., should be

$$\frac{D^2}{100\times9\times6\times6}(K-A).$$

This, with the rest of the same paragraph, is equivalent with expression (23) of same article. In the single case, when D=100, this formula reduces to

$$\frac{D}{9\times6\times6}(K-A),$$

the last term of (22), which by mistake was used.

The symbol (20), in last line, left column, p. 472*b*, should be omitted.

Between second and third lines, right column, p. 468, insert—varies as a quadratic function.

The formula for center of pressure on submerged circle, middle of left column, p. 472, is for case when the plane of circle is vertical.

In the second formula from foot of left column, p. 420, May No. of this Magazine, the second minus sign should be the sign of equality.

In formula (13), p. 296, April No., the term $x(r-c)$ should be $x(p-c)$.

ELECTRIC LIGHTING IN ENGLAND.

From "The English Mechanic."

WHEN the committee was appointed to inquire into systems of electric lighting, it was pointed out that such an inquiry could be of little utility, because all the information to be gleaned was already known. As it happened, the committee scarcely reached the sixth witness before obtaining statements from experts which would have been of great value to the shareholders in gas companies if made some months ago. So many men have turned their attention to the subject; so

many machines are now actually in use, that if the electric light once more retires, it will be a long time before it is resuscitated. We do not think it probable that it will retire, for although it is not impossible that Mr. Edison's inventions in this connection have been much overrated, the exact position of the electric light is beginning to be understood, and there is a very wide field of usefulness open to it without coming into contact with gas as a rival. If it can be utilized in such places as the Albert Hall, theatres, &c., managers will not study economy too rigidly, for they know well that the intolerable heat of the gas, and the absence of any satisfactory ventilation keep many persons away. A few pounds extra per week will not, therefore, prevent the introduction of the light, if a system thoroughly satisfactory in other respects can be devised. We have previously alluded briefly to the evidence of Professor Tyndall and Dr. Siemens, and the opinion of the latter, no matter how much he may be pecuniarily interested in the success of the new light, deservedly carries great weight, and will be accepted as a trustworthy statement in favor of a change in our method of illuminating wherever the new system is applicable. Mr. Conrad W. Cooke is also clearly on the side of the electric light, and did a useful service by pointing out that the most complicated apparatus was not necessarily the one most likely to get out of order. A locomotive, for instance, is a wonderfully complicated machine, considering the conditions under which it works, but a break-down in consequence of its complications is a rare event indeed in railway working. Hence, in adopting the electric light it would be unwise to discard apparently complicated apparatus which has been well-tried, for the more simple devices, unless it can be demonstrated that they really give better results. Speaking of the Serrin lamp, Mr. Cooke said it might seem "frightfully complicated" to the inexperienced, but as a matter of fact we know that it is one of the best regulators at present invented, and its one fault is that with indifferent carbons it makes a noise, which, as Mr. Preece put it, would be likely to disconcert singers. The carbon difficulty is really a crucial point, for if good homogeneous electrodes can be made at a cheap rate there are several lamps which would at once come into extensive use; but if a better material could be discovered, electric lighting would take quite a leap in advance. This branch of the subject is worth a good deal of experiment, for, as we have previously pointed out, the inventor of a really good substitute would undoubtedly do a large and profitable business. Mr. Cooke alluded to the difficulty of lighting streets, for to subdivide the current involved a great loss, whereas if large and powerful lamps were used on single circuits there is more light than is required in the vicinity of the lamps, and not enough, perhaps, at the limit of the range. Much has been written and said as to placing the lamps higher than in the experiments already made, but those who make that suggestion forget that the illumination would decrease as the square of the distance. It may be that the lamps on the Embankment were not high enough; they were certainly badly placed, for one-half the light went to illuminate the darkness of the river; if they had been placed on more lofty posts, the area illuminated might have been increased, but at the same time the intensity of the illumination would have been decreased. We have to find out the position most advantageous. Among the statements elicited from Mr. Cooke we find the following:—That there is a limit as to the length and strength of carbons, and that the finest made were a millimetre in diameter, and a metre in length; that where the electric light was used there would be an almost unappreciable amount of carbonic acid produced; that the light was well adapted for use in drapery stores, and that its spectrum was purer than that of the sun. Mr. Douglass also gave evidence in the form of a *résumé* of his paper recently read before the Institution of Civil Engineers, in which the work done by the Trinity Board in adapting the light to special purposes was detailed. Then came Mr. Preece, who stated that he had not yet been able to devise a method of utilizing the light for the purposes of the Post-office, though as they spent £7,000 a year for gas they would be glad to do so, especially as in one department they had to work all night, and some difficulty was

experienced in getting rid of the vitiated air. To fit up the electric light in the telegraph galleries it is necessary that the lamps should be equal to at least 1,000 candles; they must give an absolutely steady light, and be capable of burning all night without requiring attention. The last condition it appears involves a duration of eighteen hours, and Mr. Preece said that at present he had not found any system capable of answering those three requirements. The difficulty was in the lamps. The Serrin gave the requisite brilliancy, but not the durability; the Wallace would burn for a week, but was not steady; the Werdermann was steady, but did not supply the other essentials. Mr. Preece does not think the electric light suitable for street illumination, and corroborated the statements of Mr. Cooke upon this point. By working the problem out on paper he had arrived at the conclusion that a street 1,000 ft. long would be better lighted by forty gas-lamps of 15-candle power than with one electric lamp of 6,000 candles; but in symmetrical spaces, such as squares, a single light would be economical. From Mr. Preece's evidence it also appears that it would be practically impossible to run lighting wires anywhere near wires used for telegraphic purposes; they must be at least 6ft. apart. Asked as to the distance apart the telegraph wires were placed, Mr. Preece said that at first it was only 6in., but as work increased and the apparatus improved in delicacy the distance had to be increased to 13in., and more for long circuits, but they could transmit messages from London to Ireland at the rate of 150 words a minute, which would be increased next year to 200, but if wires for lighting purposes were placed near it would reduce the carrying capacity of the telegraph wires to 61 words per minute. To place the wires underground would increase the cost three or four times, and to some extent would diminish the transmitting power.

Dr. Hopkinson stated that he had endeavored to ascertain what the several machines in use would do under varying electrical conditions, and what current could be produced at given speeds and resistances. He found that on an average about 87 per cent. of the mechanical energy imparted to the machine was converted into heat, but it was only a portion of this heat that was available for producing the light, about 50 per cent. of the mechanical energy being lost in heating the machine and wires. Dr. Hopkinson considers that a great deal remains to be done before the electric light can be extensively used, and that the scientific considerations had scarcely been touched in a satisfactory manner. M. Berly, engineer to the Société Générale, explained that the light on the Viaduct had not been so successful as that on the Embankment, owing to the French workmen having given way to habits of intemperence—another defect which it is to be hoped is peculiar to the system employed. The cost of the Jablochkoff candle in England was 5*d.* per hour, but in Paris it was only 3*d.*—a statement we do not pretend to understand. Mr. Schoolbred said that he had 20 candles which had replaced 230 gas burners; the advantages were that colors could be distinguished at night, the ceilings were not discolored nor the goods damaged, the atmosphere was not heated, and there was no danger from fire. There were some disadvantages; for instance, on one occasion all the lights went out; but the advantages outweighed the disadvantages. It appears then that Mr. Schoolbred is satisfied with the Jablochkoff candle, and has determined to persevere with it in spite of the cost, which is, during the winter 37*s.* 3*d.* per night, and 9*s.* 10*d.* in the summer, for 20 "candles," which, having replaced 230 gas burners, are presumably each of about 150 candle-power. If a business man is satisfied with the appliances at present available, it will be seen there is much reason to think that in certain establishments the electric light will be preferred, even if it is more costly than gas, simply on account of the advantages above pointed out. There is, consequently, sufficient encouragement for inventors, and the next twelvemonth ought to witness a great step in advance if the electric light is really to become common in shops and streets.

An exhibition of silk and cotton spinning and weaving machinery, textile fabrics, metal work, porcelain, and chemical products will be opened at Winterthur on July 27th.

IRON AND STEEL ARMOR PLATES.

From "The Nautical Magazine."

THE contest between guns and armor has now been going on for more than twenty years, and the ultimate result appears to be as far off as ever. While in place of the old 68-pounder we now have monster guns weighing 80 and 100 tons, and throwing a shot of nearly a ton weight, the thickness of armor has increased from 4½ inches in the *Warrior* to two feet in the *Inflexible*. It is doubtful if the limit of thickness of armor has even yet been reached; the limit of size in the gun certainly has not. Still it must be remembered that although we may expect to hear of much larger guns than any at present in existence, the difficulty and danger of fighting these monsters on shipboard will be very great, as has been recently forcibly exemplified by the unfortunate accident on board the *Thunderer*. It is confidently expected on the other hand that something may be gained on the armor side of the question by the adoption of some material for armor plates which shall offer more resistance to shot than the rolled wrought-iron plates hitherto used. In an article some time ago, we described the process of armor plate manufacture and the construction of the armored sides of modern ironclads; since that time the material used for armor has continued to be soft puddled iron, and no very great change has taken place in the arrangements of the iron frames and skins, and wood backing which form the "protected side" of an ironclad. Thus in the French ship *Devastation*, which is the most heavily armored full-rigged ironclad, the side consists of an inner skin 1½ inch thick, outside which comes teak backing of 12½ inches, consisting of logs running in a fore and aft direction, and then 15 inch armor plates. The Italian *Dandolo* and *Duilio*, which have thicker single plates than any other vessels, have an inner 1½ inch iron skin, backing 17½ inches thick, consisting of teak logs placed vertically, and having vertical iron frames between them at intervals, the armor plate outside of this being 21½ inches thick. The English *Inflexible* has a side made up of an inner 1½ inch iron skin, backing 6 inches thick, made up of teak plank placed fore and aft, with iron stringers between them at intervals, then armor plates 12 inches thick, then a backing or rather a cushion of teak 10½ inches, consisting of logs placed vertically, and an outer armor plate 12 inches thick. The *Inflexible* is the first instance of the employment of two thicknesses of armor with wood between them on the armored side of the ship, but the *sandwich* system, as it has been called, has been followed in several cases in the construction of turrets, in the English ships *Devastation*, *Thunderer*, and *Dreadnought*, and also in the Russian *Peter the Great*. We believe this has resulted from the practical difficulty of bending the very thick armor to the extreme shapes which are required for turret armor, or perhaps we should rather say to the difficulty of bending it without injury. The Italian Government however have even the turret armor of the *Dandolo* in single plates nearly 18 inches thick.

While thus armor has been increased from 4½ inches to 24 inches, the same material has been used throughout. The quality of that material is much better than in the early days of armor plate trials, as is exemplified by the fact that, in the early Shoeburyness experiments, the plates were very liable to crack through the armor bolt holes, so much so that many devices were tried with a view to securing the plates in such a way as not to require holes through the armor. The quality of the armor has been so far improved, however, that for some years past the holes for armor bolts have ceased to be seriously objectionable.

Within the last few years, several proposals have been put forward for introducing new materials for armor plates. We will not spend much space in notic ing one of the first, which, indeed, had more especial reference to armor used in land defenses than on ships. It is ably described in a paper read before the Institution of Naval Architects, in 1877,

by Commander H. H. Grenfell, R.N., and is due to Herr Grüson, of Magdeburg, in Germany. It is, to use cast-iron of superior quality for armor plates, and to cast them in chill molds. "These iron molds," it is said, "chill the surface of the plate and give it great hardness and elasticity. When sufficient metal to form the plate has been poured in, molten metal is run round the mold itself. By these means, whilst the surface of the plate is chilled by contact with the mold, the interior is prevented from cooling too rapidly, and the particles of iron have time to assume their natural positions, with the result that the interior and inner side of the plate retain the high degree of tensile strength which belongs to the iron used." Wrought-iron plates are partly penetrated by shots which cannot get through them, and thus would be liable to be destroyed by a continuous fire from guns of comparatively small caliber. The advocates of chilled cast-iron armor believe that it would be absolutely impregnable, as regards guns of less caliber than those capable of penetrating it. It is, however, admitted that a thicker plate would be required than in the case of wrought-iron to resist complete penetration by any given gun, and for this reason alone it appears altogether improbable that it will ever be used for ships' armor plates. It is true it would cost much less than wrought-iron; but the great consideration in ironclads is weight, and the armor which is really the cheapest in the end is that which, weight for weight, is the most effective. This is due to the fact that greater weight of armor necessitates larger displacement, and this requires a larger *area* of armor, more powerful engines, &c., which again further increase displacement, and so every additional ton of armor tells much more in the total expense of the structure than in its own prime cost. Herr Gruson's cast-iron armor was tested by shot from some of the Krupp guns, and although it was reported to be a success, the German Government do not appear to think very much of it, seeing that they have used ordinary rolled plates, even on land defenses constructed since the trials. Cast-iron armor was also tried at Spezzia, in the notable series of experiments made by the Italian Government, in November, 1876, but the results were not at all satisfactory.

The proposal to adopt cast-iron as the material for armor plates, although it led to no immediate result, served to direct attention to the question of the defects of wrought-iron, and also to the consideration of means for avoiding them, without, at the same time, sacrificing the well-known advantages of the old material. The adoption of mild steel in place of puddled iron for the frames and skin plating of war vessels has also served to bring about trials of new materials for armor. These trials are described at length in an able paper recently read before the Institution of Mechanical Engineers, by Captain C. O. Browne, R.A., of Woolwich, and entitled, "On the Construction of Armor to resist Shot and Shell." Captain Browne's paper gives an admirable resumé of the present state of the armor question, and he describes the more important experiments in England upon wrought-iron armor of the last few years, as well as the Spezzia experiments upon steel armor plates, and some more recent trials of composite iron and steel armor. First he compares the action of different kinds of guns and projectiles upon armor. The first large guns which were used in his country, and those which were for a long time after favored in America, were designed to throw a large shot with low velocity. Their action upon armor was to break it up, and this method was successful with the inferior plates at first tried. We remember seeing the effect of a large gun known as the Horsfall gun, at Shoeburyness, upon a target representing the side of the *Warrior;* a breach was made in the target, but it was a smash such as suggested a waste of force. As better wrought-iron armor was produced of greater thickness, it was seen that the best method was to pierce or punch rather than smash the plate, and for this purpose the present style of heavy gun throwing a comparatively small shot with great velocity has obtained. The first projectiles, and those best adapted for smashing, were spherical. Flat-headed cylindrical shot were then tried, and they are most effective merely for punching a hole in a plate, but a cylindrical shot with an

ogival head has been found most effective in penetrating the ordinary armor and backing. The flat-headed shot punches a hole through the plate and cuts out a disc from it which meets with great resistance in the wood backing. The pointed shot on the contrary punches a hole, but instead of tearing out a disc cleaves the plate and passes through it, and then through the wood backing. This projectile finds out especially the peculiar weakness of the *sandwich* system, and Captain Inglis states on this point as the result of experiment, that the resistances of armor of 7½ inches thick made up by one, two, or three plates, varies respectively as 100, 96, and 89; and that a single plate 17½ inches thick is about equal to three 6½ inch plates separated by 5 inch layers of teak. If such be the case, the English *Inflexible* with two 12-inch armor plates must be superior to the Italian *Dandolo* with one plate 21½ inches thick; but there is a farther consideration, it is exceedingly difficult to make reliable armor plates of the greater thickness, unless they be narrow, and one result of the Spezzia experiments was to prove the great weakness of narrow plates, for every one of the thick plates broke across when fired at by the 100-ton gun.

In comparing the effect of guns upon plates a formula is used deduced from practical experience, and by which the efficiency of each gun is expressed in terms of the thickness of wrought-iron plate it is capable of penetrating. The resistance offered by armor to penetration was for some time considered as varying with the square of the thickness; it has been determined within the last few years that the resistance varies with the $1\frac{6}{10}$ths power of the thickness, and thus the gain of extra thick plates is less than was formerly supposed. Using this rule, and ascertaining also the striking velocity of shot from a given gun at a given range, the weight of shot also being known, the amount of penetration of a plate of average quality may be made a matter of calculation, and plates may be matched against guns. If a gun is not capable of piercing through a given plate, it will obviously penetrate it to a less depth than it would be equal to if the plate were only just a match for it, and this being taken into account, the results of successive experiments come very near the predicted result. It is interesting to notice the details of some of the experiments as showing exactly what may be expected of armor as regards the effect of guns already carried on board ships.

The 38-ton gun, as at first tried in 1876, was fired with a charge of 130 lbs. of powder and a projectile weighing 812 lbs. By the formula used by the Director of Artillery, its calculated power of penetration would be 19½ inches; it did actually pass through a *sandwich* target having three plates each 6½ inches thick. Afterwards the 38-ton gun was altered so as to take a larger charge of powder; its calculated penetrating power was then 21 inches, and it was opposed to a target having a total of 26 inches of iron; it penetrated this to a depth of 20 inches. The gun which recently burst on board the *Thunderer* was a 38-ton gun, and there are no larger guns than this afloat at present. It is therefore of some interest to know that its limit of penetration under the most favorable circumstances is 21 inches. The *Inflexible* is the only ship in the English Navy which has armor exceeding this thickness, and the *Dandolo* and *Duilio* are the only war ships in the possession of any foreign power which come up to it. Thinner armor of course is of some use against the 38-ton gun when the destructive shell is substituted for the shot, which merely penetrates.

Similar results were obtained by the tests of the 80-ton gun, which has a projectile weighing 1,700 lbs., and was in the first experiments fired with a charge of 370 lbs., which gives a calculated penetrating power of 28 inches. It was tried against a *sandwich* target consisting of four 8-inch plates, and actually penetrated 25 inches. The 80-ton gun was also chambered to take a larger charge of powder, when its shot would, by the formula, go through a solid plate 30 inches thick. It was tried against a target containing 32 inches, which was more than a match for it, and actually penetrated as far as 27 inches. Experiments were also made with shells both from the 38 and the 80-ton guns, but the experiments were made upon unbacked plates, which circumstance detracts much from their value. On this point Captain

Browne remarks:—"It would be of great practical value to our fleet if it were known exactly what thickness of armor was sufficient to cause even the largest shell to explode, before it had power to fire the backing and wood of the ship; because if a vessel were rendered secure against being set on fire, she might stand a great quantity of shot fragments and langridge passing through her side. Probably all our newest ironclads, say those carrying over 12 inches of armor, are in this condition of comparative safety, perhaps many more; in any case this would seem to be a subject well deserving further experiment."

The most effective weapon against wrought-iron is, as we have said, a comparatively small shot at high velocity, and the most effective projectile one which is best adapted for punching. The cast-iron armor to which we have referred is of an exactly opposite character, difficult to punch, easy to smash. Captain Browne dismisses it from consideration as a material for ship's armor. He says it has been used in much greater thickness than wrought iron, and, for a time, shot produces no apparent effect, but after continued fire it cracks, and soon after crumbles to pieces.

The information which we have as to the efficiency of steel armor is partly derived from the trials made with the 100-ton gun, by the Italian Government, at Spezzia. A detailed account of these experiments was given by our Italian contemporary, *Rivista Marittima*, in the number for December, 1876. Wrought-iron armor plates of English manufacture, 22 inches thick, were used on some of the targets, and on others were steel plates of the same thickness, manufactured by Schneider and Co., of Creusot, in France. We are not informed of the precise character of the steel, but we should suppose it was hard steel, and it appears to have been manufactured by the Bessemer process, and afterwards by hammering. The result of the experiments was that the shot from the 100-ton gun went completely through the iron plates and the backing behind them, showing that there was much greater penetrating power than was used up by the plate, but it only just penetrated the steel plate. All the plates, however, were broken. In some other experiments with much smaller guns, the iron plate was partially penetrated, but little injured, while the steel plates showed signs of cracking, which clearly prove that though superior to the iron as regards one very heavy blow, they were much inferior in powers of resistance to the fire of comparatively small guns.

There are also some important results of more recent English trials of new kinds of armor, but we think they are anything but conclusive. The first series were carried out at Shoeburyness, the second on board the *Nettle*, at Portsmouth. Four different kinds of plates were tried, three of them being combinations of iron and steel, the fourth was a mild steel plate. One of the combination plates proposed by Sir J. Whitworth was of soft steel with hard steel plugs screwed into it at intervals. It was expected that the plugs would break up the shot. This plate, however, was not made in the way desired by the inventor, and the same was said also of the other two combination plates. The first of these was made by running molten steel between two wrought-iron plates which were at a welding heat, one iron plate was $\frac{3}{4}$-inch, the other $1\frac{1}{2}$-inch, and the total thickness 7 inches. The second of 5 inches of steel and 4 inches of wrought-iron was manufactured in a similar manner. The result of the trials appears to have been that all four of the plates resisted penetration better than iron plate of corresponding thickness, but were more liable to rapid destruction from continual fire. So far the conclusion derived from the Spezzia trials appears to hold good for all armor in which steel is used.

As regards power of resisting long continued fire, iron armor appears fully to hold its own, and according to our present lights, steel-faced armor will only be adopted, from the consideration that no plate in an engagement is likely to be exposed to anything like the extreme trials made for experiment. It may, therefore, prove the best policy to have plates which will resist penetration rather than those which are not liable to split and crack from continued battering. It has recently transpired that, with this view, the Admiralty have decided to use steel-faced armor experimentally on the turrets of the *Inflexible*. It will be

manufactured by first rolling an iron plate, and then pouring fluid *hard* steel upon the red hot iron, it being believed that by this process the two materials become welded together. The plates are to be made at the Cyclops Works, Sheffield. In consequence of the uncertain results of the new method of manufacture, the Admiralty have wisely determined to subject every plate to the firing test. It is the custom at present to take at random one plate from a parcel of armor plates and have it fired at, the acceptance or rejection of the parcel depending upon the result. The new compound plates will be made of extra length to admit of one end of each plate being fired at, and then the injured portion will be cut off and the plate used, if the result be satisfactory. By this means a series of experiments will be made upon the resisting powers of steel-faced plates, and upon the results their future will materially depend. The Italians have decided to use steel armor to a large extent in their most recent ironclads, the *Italia* and *Lepanto*, but the steel in this case is manufactured by M. Schneider, and is somewhat like the mild steel lately brought into use in shipbuilding. If the compound armor should not succeed, we would suggest that a solution of the question may possibly be found in the use of a metal intermediate between the mild steel, used in ordinary ship building, and hard steel, giving up some of the tenacity and endurance to be obtained only in wrought-iron or mild steel armor, and obtaining a greater resistance to penetration in exchange.

We believe that none of the ironclads building at present for our Navy will carry thicker armor than the *Inflexible*. The *Ajax* and *Agamemnon* are really reduced copies of the *Inflexible*, and carry thinner armor. The time will come, however, when the question of a further increase in armor thickness will have to be considered, and it will be well if the question of the best material is finally settled before that time.

HOUSEHOLD SANITARY ARRANGEMENTS.

From "The Building News."

In his last Cantor Lecture on "Dwelling Houses: their Sanitary Construction and Arrangements," Dr. Corfield took up the subjects of filtration of water and dry systems of removing refuse matters. The process of purification of water by filtration was, until recently, misunderstood. For a long time it was thought that water, in passing through a pervious material, was simply mechanically strained to the extent of separating from it the grosser suspended particles. When it was noticed that some of the dissolved matters were eliminated from the filtered water, it was still supposed that these accumulated in the filter, and that they would in time choke it up. The action of a filter was, however, not only to strain the water, but so to subject it, when finely divided, to the action of the air, that organic matters, whether suspended or dissolved, were oxidised by it and changed from putrescible substances to minerals no longer liable to change, and incapable of affecting the health of those drinking them. These facts explained the reasons why filtration to be thoroughly effective, should be both downward and intermittent—downward, because then the water descended by its own weight in minute streams, and was less likely to be forced through the porous material *en masse*, driving the air before it; and intermittent, to give time to the filtering substance to re-absorb air in place of that used during the purification of the water. A compensatory advantage of upward filtration was that when it was adopted there was some guarantee that all the water had actually passed through the filter. In illustration of the necessity for sharply looking after all household filters, to insure that they were in good order and in use, Professor Corfield mentioned that a London medical man, who was very particular about sanitary matters, suspected that

the filtration of his drinking-water was not so thorough as it ought to be. On examining his cistern he found that the filter had been carefully adjusted so as to purify the water passing into the servants' water-closets, whereas the domestic supply for drinking purposes was not submitted to the process.

Having explained the principles of filtration by familiar illustrations, and referred to Dr. Frankland's experiments, the lecturer proceeded to describe a number of filters exhibited on the table. In those of the London Water Purifying Company, the water passed upwards from the large cistern through pores in a vase; from thence it passes out at the top through a little cup full of holes, and so into pipes by which it is drawn off into the pipes upon the siphon principle. In these filters all the water used must have passed through the filter, and it would continue in action for an almost indefinite period.

Concerning the silicated carbon filter, the opinion was pronounced that the filtering material was exceedingly good, not being liable to contain living organisms. For filtering purposes both animal and vegetable charcoal were employed. The latter material was very inferior—it not only gave off salts into the water, but was less effective in straining the liquid. Animal charcoal was not always sufficiently burnt; and when any animal substance remained uncalcined in the center of the cake of charcoal, it became a breeding-place for minute red worms. In using charcoal, therefore, it was necessary to see that it was of animal origin, and that it was thoroughly burnt. It ought to be frequently cleansed, and occasionally scraped. Sponge was often used, as it was an exceedingly unalterable substance: but it needed more frequent washing, or, better still, should be replaced at short intervals, as it harboured small worms. In too many filters, much of the water passed over the surface only of the porous material. The best forms of charcoal filter were those in which two blocks were used, the first acting as a strainer. A well-known charcoal filter was Atkins', known as the Admiralty pattern, of which several varieties were shown. In almost all filters the water should be run off every night, to allow of re-aëration. This must not be done with the spongy iron filters of Bischof, in which the material must always be kept under water. By means of diagrams and specimens, the action of these filters was explained, it being shown that the water entered the filter by a ball-cock arrangement, and passed down by a tube to near the bottom of the vase; it then rose through holes in a plate through the spongy iron, and was drawn off at the top. In passing through the iron the water took some of its particles up, and was, therefore, afterwards run through a layer of prepared sand. In order to aërate the water, it was next spurted through a minute hole, falling as spray into a pure-water reservoir. The principles of action of this filter were not yet clearly understood, but its results were the destruction of organic substances in a different manner to that effected by using either charcoal or sand. In the aerating filter of the Sanitary Engineering and Ventilating Company, the air that passed out of the pure-water chamber rose through the filtering material, and hence there was no need of the tube for the exit of air provided in almost all filters. In this filter water passed into a loose vase, and through a cake of silicated carbon, being subsequently squirted upon other loose filtering material. The plate supporting this second mass, instead of being flat, as in ordinary filters, was raised in parts, with small holes both in the elevated and depressed portions, so that the air displaced by the water escaped through the higher portions of the plate. For use in a room the common glass vase containing a cake of charcoal was suitable, as its perfect cleanliness could be seen at a glance. An improvement was a handle to the upper vase, so that when raised it did not drip. A good method for filtering rain-water, for use in country places, was that designed by Professor Rolleston, of Oxford. It was a tank divided into a large and small compartment, with a layer of filtering material passing through both divisions, and resting on a perforated frame. The rain-water was received near bottom of the smaller compartment, and, rising through the filtering medium, flowed over the diaphragm into the large compartment, where, passing by gravitation through the second filter-bed, it flowed away. The water was thus

subjected to both upward and downward filtration. A waste-pipe, to obviate overflow, was an essential to this filter.

The lecturer then passed on to his second topic, the removal of refuse from houses by "dry systems." "Dust" ought to be nothing but what its name imported, household dust and ashes; but, as a fact, all kinds of refuse found their way into the dust-bin, creating much nuisance. All organic refuse from the kitchen ought to be placed on the kitchen fire at night, when it would help to light the fire in the morning, and would be inoffensive, as every one could see by experiment. The difficulty of dealing with dust was a growing and increasingly expensive one. A few years since, when it was largely used for brick-making, it was a valuable product, but now, contractors, instead of offering considerable sums for the privilege of removing it, required payment for taking it away. Thus, at Islington, the contractor a few years since offered £2,200 a year for the dust, and this year the accepted tender cost the parish £4,057. One of the first sanitary laws was that all refuse matter should be removed as speedily as possible, but owing to the expense of carting away a valueless material our dust-bins were emptied as seldom as possible without becoming an absolute nuisance. Where practicable, dust-bins should not be allowed to abut on the walls of a house, and in no case should a rain-water pipe be permitted to pass through them; much injury to health resulted from a combination of these errors. If the space was so limited that the bin must rest against the house, it should be well cemented to prevent the percolation of air through the walls, and a rain-tight cover (happily made compulsory in the metropolis) should be fitted to it. But he must pass on to speak upon our methods of treating excretal matters in, and their removal from the, house. The very name of these methods, "conservancy plans," was self-condemnatory, for the householder's aim should be to get rid of excretal and other refuse as speedily as possible. The first of these methods was by digging pits or cesspools in the adjacent ground, or even under the house, as a receptacle. When these were in fashion, it was thought so much the better if the soil were porous, for then the liquid matter would drain off, and they would need emptying the less often. The inevitable result was, that in loose soils the wells became contaminated, and cholera and typhoid and other fevers prevailed. Opinions changed, and cesspools were afterwards made with impervious walls, so that the contents were kept in, connection being sometimes made with a land drain or sewer. The last modification was yet largely practised in Paris for the sake of the manure; in that city, as visitors had seen, open-mouthed pipes passed from every floor to the cesspool, and as the only ventilation was by pipes to the roof level, the method was exceedingly offensive. In that city the receptacles were emptied by means of air-tight carts, previously exhausted of air, and attached to the cesspool to suck up the contents—a practice no one who had observed it in operation would wish introduced into England. In many parts of this country the dust-heap was made the receptacle of all refuse, the liquids being absorbed by the ashes. In some towns these "midden heaps" were of enormous size, as in Liverpool, and were even suffered to accumulate in the houses. Wherever they existed the mortality, especially amongst children, was very great. The improvements in these dry systems were always twofold, consisting—first, in making the receptacles smaller; and second, in rendering them impervious to water. The first alteration necessitated more frequent cleansing; the second insured that the refuse should be less liable to moisture—one of the essential conditions of decomposition. Cesspools were, as knowledge of sanitary laws increased, reduced to movable receptacles, as in many parts of France, and the liquids were allowed to pass off into drains and the solids removed, as in Chesshire's system. Pails and tubs were placed below the seats of closets, as at Edinburgh, Manchester, and Birmingham. The danger of these plans was that these foul substances were allowed to remain in the house too long. Such receptacles should have a spring lid, with india rubber edges, to enable it to fit as tightly as possible. At Hull, a watertight receptacle was placed beneath each closet and periodically removed, and even this small improvement had led to a reduction of the death-rate of that town. Dr. Bayliss, medical officer of health for

West Kent, had devised a shaft rising from the receptacle above the roof; the lecturer had examined instances of it in use, and considered it worked well in cottages. Morrell's self-acting cinder-sifting ash closet (of which a model was shown), had attached above and behind the closet a receptacle for cinders, of which the larger ones were retained in a sieve, and might be re-burnt. By the movement of the seat the ashes were sifted and fell into a hopper, being jerked upon the deposit when the seat rose, and so rendering it comparatively inoffensive. An undoubted advantage in this closet was that it separated the large cinders for re-use on the fire. The Goux system consisted of a double pail placed beneath the closet, having an absorbent material between the two pails. The dry-earth system was brought into prominent notice by the Rev. Henry Moule. He pointed out that dry earth formed a perfectly odorless compound with excretal matter, and that it could be used again and again if re-dried. For large communities, however, the system was perfectly impracticable. First there would be considerable difficulty in procuring in large towns a sufficient quantity of dry earth. Then there would be further difficulty in getting rid of the compost, owing to the fact—only admitted after considerable experiment—that it was not a valuable material manurially. The organic substances were so decomposed into their constituent carbonates and nitrates, some of the latter being probably given off as free nitrogen, that after the earth had been re-used six or seven times it possessed no greater agricultural value than ordinary garden mould. An insuperable objection was that in towns it would be liable to be used by careless persons, who let slops and other liquid refuse mix with it, and so hasten decomposition, and the apparatus itself might get out of order. There was also the peril, the extent of which was yet unknown, that although the substances were deodorized they might not be disinfected, and so might propagate disease. The system was, however, the best for temporary collections of people, as at volunteer encampments or cattle shows, and might be used in isolated country houses. A similar system had been adopted for ages in China, and had been the means of enabling that land to maintain an enormous population without rendering the whole country barren. Professor Corfield announced, in closing his address, that in the next two lectures the water carriage systems of removal would be considered.

STREET PAVEMENTS.

A Paper read before the Institution of Civil Engineers.

STREET CARRIAGEWAY PAVEMENTS. By Mr. GEORGE F. DEACON, M. Inst. C.E.

WOOD AS A PAVING MATERIAL. By O. H. HOWARTH, A.I.C.E.

With respect to the figure of stone sets, the author explained that in order to secure stability their depth should be greater than any other dimension; but the length should be greater than the width in order to facilitate breaking joint. His conclusions might be thus summarized—Hard stone, in which joints were unnecessary for foothold.

	Depth. In.	Width. In. Sets.	Length. In. In.
Sets for moderate traffic	6 to 6½	4 to 14	5 to 7
Sets for heaviest traffic	7 to 7½	4 to 14	5 to 7

Softer stones, in which joints were unnecessary for foothold.

	Depth. In.	Width. In. Sets.	Length. In. In.
Sets for light traffic or inclines	6 to 6½	3 to 14	5 to 7

A crucial examination of many classes of pavements had satisfied the author, in 1871, that those jointed with asphalt retained their figures better, and wore out less rapidly, than any others. This method of jointing, however, was often very indifferently performed. Since that date all the Liverpool pavements had been jointed in this manner with great advantage; and all those subject to heavy traffic had been constructed with Portland cement or bituminous concrete

foundations. The mode of constructing the foundations and pavements differed in some important respects from that generally adopted, and was fully explained. The Portland cement concrete was mostly prepared in a yard, and not in the street where the work was going on; and the author had proved, by a large number of conclusive experiments, that no loss of strength, but probably a slight gain, arose from allowing such time as was occupied in cartage to elapse between mixing and placing *in situ*. Carriageways of bituminous concrete, or asphalt macadam, were next described. The smaller stones used for the upper layer of such pavements should not be much harder than the asphalt itself. A large area of this pavement had been constructed in Liverpool, and on sanitary grounds the system would probably be extended over many back streets.

After describing his experience of wood pavements in Liverpool, the author drew the conclusions that like stone pavements, they should be provided with concrete foundations, the joints should be very close, and the blocks should be creosoted.

Much difference of opinion existed as to the best mode of finishing or blinding the surface of macadamized pavements. Under a 15-ton steam roller, preceded by a watering-cart, 1,200 yards of trap-rock macadam, without blinding, could only be moderately consolidated by twenty-seven hours' continuous rolling. If blinded with trap-rock chippings from a stone-breaker, the same area might be moderately consolidated by the same roller in eighteen hours. If blinded with silicious gravel from $\frac{3}{4}$ inch to the size of a pin's head, mixed with about one-fourth part of macadam sweepings obtained in wet weather, the area might be thoroughly consolidated in nine hours. Macadam laid according to the last method wore better than that laid by the second, and that laid by the second much better than that laid by the first.

In order to compare the wear of different classes of pavements, the author had reduced the traffic to tons per annum per yard width of the carriageway, and in the following tables he compared the total annual cost of various pavements when subjected to a standard traffic:

(*See Table on following page.*)

With a traffic of 40,000 tons per annum for every yard in width of carriageway, the figures for the last three pavements were as follow:

(*See Table on following page.*)

From inquiries made with reference to the loads drawn by horses since the new Liverpool pavements were constructed, as compared with the loads drawn on the old pavements, and without giving credit for the great reduction of wear and tear of horses and vehicles, the author estimated that there was a saving in the cost of cartage alone exceeding £10,000 a year for every mile of such pavement as now laid in the Dock line of streets in Liverpool.

Of all pavements for street carriageways macadam appeared to the author to be the least satisfactory. It was the most costly, the dirtiest, and, on the average of all kinds of weather and all conditions of repair, probably involved a greater traction for a given load than any of the other systems when thoroughly well laid. Its dirtiness consisted not only in the excessive mud of wet weather, and the excessive and impure dust of dry weather, but also in the facility with which organic impurities were absorbed by it, decomposed within it, and exhaled to the atmosphere. In country roads this objection was insignificant, and no other pavement was better than well maintained macadam; but in some of the carriage-ways of the west end of London one would regard it as intolerable, had it not been tolerated so long. To the unsophisticated provincial the manner in which, on a hot July day, fashionable London rolled over her tainted macadam pavements, apparently without even smelling them, was a mystery almost as great as surrounded the fact that the metropolis, alone among the great centers of civilization in this country and in the world, still submitted with apparent satisfaction to an intermittent water supply, impure at times in almost every household, however pure the source of that supply might be, when with absolute pecuniary benefit a constant supply might be obtained.

The second paper was on "Wood as a Paving Material under Heavy Traffic," by Mr. O. H. Howarth, Assoc. Inst. C.E.

The primary point into which the con-

Description of Pavement.	Original cost per square yard at present prices.	Interest on original cost at 4½ per cent.	Sinking fund invested at 3 per cent. Compound interest.	Maintenance per square yard per annum.	Scavenging per square yard per annum.	Graveling per sq. yard per annum.	Total annual cost per square yard.	Remarks.
	s. d.	*d.*	*d.*	*s. d.*	*d.*	*d.*	*s. d.*	
No. 1. Hard stone. Gravel joints. Hand-pitched foundation..	12 1	6.5	1.8	0 1.0	4.2	—	1 1.5	Old Liverpool pavements.
No. 2. Hard stone. Asphalt joints. Portland cement concrete foundation.....	15 1	8.2	0.6	0 0.25	2.4	—	0 11.45	Now constructed in Liverpool for heavy traffic.
No. 3. Hard stone. Asphalt joints. Bituminous concrete foundation.....	14 10	8.0	0.6	0 0.25	2.4	—	0 11.25	Ditto ditto.
No. 4. Medium stone. Asphalt joints. Portland cement concrete foundation.....	15 1	8.2	3.7	0 0.5	2.4	—	1 2.8	Ditto for light traffic, or steep gradients, and junctions of streets.
No. 5. Medium stone. Asphalt joints. Bituminous concrete foundation.....	14 10	8.0	3.7	0 0.5	2.4	—	1 2.6	Ditto ditto.
No. 6. Bituminous concrete	3 9	2.0	—	1 6.0	2.4	—	1 10.4	Ditto for back streets, and for street carriageways of very light traffic.
No. 7. Wood, creosoted. Bituminous concrete foundatiun.....	15 1.5	7.5	10.1	0 1.0	2.7	5.0	2 2.3	Prices if constructed by Corporation.
No. 8. Macadam hand-pitched foundation..	6 9	3.4	—	2 0.0	8.0	—	2 11.4	In Liverpool for the suburban roads.

Description of Pavement.	Original cost per square yard at present prices.	Interest on original cost at 4½ per cent.	Sinking fund invested at 3 per cent. compound interest.	Maintenance per square yard per annum.	Scavenging per square yard per annum.	Graveling per square yard per annum.	Total annual cost per square yard.
	s d.	*d.*	*d.*	*s. d.*	*d.*	*d.*	*s. d.*
No. 6. Bituminous concrete	3 9	2.0	—	0 9	2.4	—	1 1.4
No. 7. Wood	15 1.5	7.5	4.3	0 10	2.7	5.0	1 8.5
No. 8. Macadam.....	6 9	3.4	—	1 0	8.0	—	1 11.4

flicting details of the street pavement problem could usually be resolved was simply this: That the conditions of road surface demanded by the two main elements of street traffic, viz., the power and the load, were almost essentially opposed. That was, the surface most favorable to the intermittent tractive action of horses was not the one best adapted for the transmission of rolling load. Te reconcile these conditions, so as to render them the least obstructive to each other, was the practical aim of road paving.

A series of observations, collected during the past three years, tended to show that against all the discrepancies which rendered comparisons of street traffic doubtful, opposite conditions had been found to arise by which they were compensated in the long run; and that,

on the whole, the effect of such minor irregularities was largely controlled by the element of weight. Upon this consideration it became evident, that the formula of direct weight per unit of roadway width was that which must afford the least erroneous datum for reducing large series of traffic observations, taken under fixed rules respecting the conditions to be noted. The system adopted by the author aimed at obtaining reliable averages, by short and definite observations properly distributed, rather than from continuous counts over an isolated series of hours. The observations were collected by half-hours only, at fixed periods throughout the day of sixteen hours, from 7 A.M. to 11 P.M. in every case; such half-hours being respectively observed again on other days at the same points and in different conditions of weather. The remaining night hours affording a traffic small in proportion, and at the same time subject to great irregularity with variable circumstances, were excluded, as vitiating the averages required. The system of short observations, while undoubtedly leading to a highly corrected comparative figure, was also found to facilitate the notes respecting weight, which were of necessity collected simultaneously with them. The traffic was divided under seven heads; for the most numerous and important of which the empty weights could be ascertained with precision, and the ordinary description of load estimated without any serious or cumulative error. These averages sufficed to show how widely the actual wear and tear upon any given roadway might be misconceived, in the light of a merely general or numerical estimate.

Experience afforded by recent trials pointed to the conclusion that the true theoretical condition under which wood should be used was that of a continuous and uninterrupted suaface. If a whole street could be conceived to be paved with a single slab or section of fir timber, the surface well inlaid with clean grit or large sand, such road would (apart from expansive action) present, without comparison, the fairest test of the durable qualities of the material.

Upon the basis of these principles the system of paving with wood, known as Henson's, was introduced in 1875, having for its object the testing of the previous theory, that artificial structural foothold was indispensable to afford a fulcrum for tractive power, as well as to show the value of real continuity of surface, by providing the nearest possible approach to an uninterrupted area of wood only. The aim of the experiment was primarily to lay the blocks "heart to heart," upon a sound weight-bearing foundation, so as to present a continuous and uniform surface of wood on end. To such a construction the only foreseen obstacle was the variable expansion and contraction inseparable from that material under varying atmospheric conditions; and this, when accumulated over a large area, would doubtless have been of sufficient extent to become detrimental to the efficiency of a road pavement. With a view to meet this, it was borne in mind that the action of capillary expansion in wood was one that must be regarded as exercised slowly, through the minutest disstances; but accumulated in proportion to the area of material subject to it. The compensation for such an expansion could therefore only be uniformly effected over a large area, by providing for the absorption of minute portions of it at the smallest possible intervals, establishing a series of minute compensations throughout the entire structure. The substance which was found in practice to be most available for this purpose was ordinary roofing-felt, from 1-16th to 1-8th inch thick, a strip of which, cut to the same width as the depth of the blocks, was interposed between each course, and thus formed a close and yet slightly elastic joint. In laying this pavement the system was adopted of driving up the blocks, as every eight or ten courses were laid, by heavy mallets and a plank laid along the face of the work, attention being given to the even range of the courses as this proceeded. The joint was thus closed as completely as possible, leaving only the actual fabric of the felt to take up the expansion, and by the mutual support of the blocks saving them from the rapidly destructive action of spreading at the edges. The protection of the wood was further enhanced by a layer of similar felt over the whole surface of the concrete foundation upon which the superstructure of wood was cushioned Results tended to show

that the several functions of this simple construction were correctly anticipated. The endurance of the wood, consequent upon its relief from vertical jarring and the mutual support of the edges of the blocks, was increased by probably not less than one-half or two-thirds. An even-grained well-grown deal, of medium weight and hardness, offered the best conditions as far as experience went.

As regarded built roads, much was generally said upon the question of elasticity above alluded to; and it is one very commonly misapprehended. Distinction was not made between two widely different theories—viz.:—Was road-elasticity requisite as it affected the traffic, or was it desirable as concerned the road itself? Within limits, it was as advantageous to one as it was detrimental to the other. Elasticity of road was for the benefit of the traffic exclusively, and not for that of the road; and the inference was that, if anywhere, it should be immediately at the surface, and there only. A totally inelastic road, whether absolutely smooth or designedly uneven, was open to objections, practically, on other grounds; and herein lay the chief characteristic which had brought wood into favor. Concurrently with a reasonable degree of durability, which admitted of being used to the utmost advantage, it presented always, and uniformly, a slight degree of surface elasticity, to the immeasureable saving of vehicles passing over it.

The standard of comparison, therefore, to which street pavements should be referred, must embody the two elements deducible from the preceding remarks—viz., the work performed (as represented by some systematic scale as suggested), and the sum total of direct expenditure upon it during a recognized unit of time. Of three materials—macadam, granite or porphyry sets, and asphalt—the first was beside the question, if only on the ground of its representing, under similar circumstances, a fixed charge of from 3s. to 6s. per superficial yard per annum. Granite was at the present time more nearly balanced with wood—excelling it somewhat in the matter of cheapness, but outweighed by it on the score of noise and injury to vehicles owing to its rigidity—the latter two defects insuperable, excepting at a cost which was but rarely bestowed upon it. Asphalt, laboring under an occasional deficiency insuperable at any cost—viz., absence of foothold—was nevertheless to be regarded favorably in point of cost, and would rank high so long as the definite solution of the problem of durability stood in abeyance. Meanwhile the above notable failing, together with the difficulty attending partial repairs, must detract from the value of the money-figure to be assigned to it.

In view, therefore, of the few materials at command, and of their several qualities and defects, the following questions comprise the chief issues to be decided:—

First.—Was the policy of paving for heavy traffic to aim at reduction of first cost and the retaining of certain alleged advantages attached to systems of continuous maintenance? or at the extinction of maintenance, and the acquisition of durability, combined with certain alleged disadvantages accompanying great resistance to wear.

Secondly.—Could a paved surface be made to fulfill the needs of tractive power by the intrinsic nature of any material, independently of designed mechanical form tending to obstruct free draught of load?

And *Lastly.*—Could the durability of any description of wood, compatible with reasonable cost, be enhanced either in construction or in maintenance, so as to place it on a commercial rank with substances of greater resistance, but of less advantage in other respects?

A NAVAL college is to be erected at Davenport for the residence of engineer students. The building will be of extensive proportions, and the contract has been let to Messrs. Pethick & Son, Plymouth, the cost being a little over £4000. It will be 190ft. long, 60ft. high, and will give sleeping accommodation and every other convenience to 300 students. It is also proposed to obtain a grant for the erection of a naval barrack at Keyham upon the completion of the college. The barrack is intended to accommodate men who are now transferred to hulks in the harbor when their ships go in dock to be repaired. The old arrangement is found to work very inconveniently.

ENGINEERING GEOLOGY.

By W. H. PENNING, F.G.S.

From "The Engineer."

II.

Methods Employed in Geological Surveying.—Geology, as a science, relates the history not only of the rocky strata of the earth's crust, but also of the animals and plants which flourished on its surface or in the ocean, at the time of their formation. An acquaintance with the organic remains enclosed, as fossils, in the strata, is of great scientific value in determining the geological age or position of the rocks, but it is to a great extent unnecessary for practical works. What is required for mechanical operations and for sanitary purposes is a knowledge of the stratigraphical geology of a district; that is to say, of the nature of its rocks and of their relation to each other. If we would make a series of drawings showing the geological structure of any locality, we must first trace upon a map the boundaries of its rocks, thus defining the area occupied by each. We must next ascertain the angle at which the rocks dip beneath the surface, and then, aided by our notes, construct a section, which shall portray their underground extension and relative position. We must further ascertain the kinds of rock of which the beds consist, by their general appearance and by the aid of simple tests in the field; or if necessary, by more complicated ones applied to detached specimens at home. Thus, to obtain an accurate knowledge of the structure of a district, and to represent and describe its geological features, three distinct and different, although intimately connected, operations have to be performed:—(1) The character and peculiarities of the strata which crop out at the surface must be determined. (2) The boundaries of the different rocks must be laid down upon a map. (3) The dip, if any, and the underground continuation of the beds must be worked out and shown upon a section. The methods adopted in the carrying out these operations are described under the following heads:—(1) Lithology—determination of rocks, minerals, &c.; (2) Geological mapping—tracing boundary lines; (3) Geological sections—showing underground extension of the rocks.

(1) *Lithology.*—It is obvious that a great deal depends upon the physical characters of a rock, when considered as a building material in itself, as a source whence such material is manufactured, or as a substance possessing any influence upon construction, or other practical operations. Therefore it is highly necessary for the geological surveyor to be able not only to determine the class to which any particular specimen belongs, but also to form some reliable ideas as to what substances enter into its composition. There are simple tests, for application in the field, to ascertain the class of rock under examination; and more delicate tests, by which the field results may be checked and extended. In many cases the directions given below will go far towards accurate determination; but it will be advisable to consult works devoted to the subject, in the examination of difficult specimens.

To ascertain the kind of any rock exposed in a quarry or elsewhere, a fragment should be detached from a part that has been least subjected to the action of the weather. Having selected a suitable portion of the rock, let a good sized piece be broken off by chisel or hammer. This should afterwards be reduced, with as little chipping as may be, into a square, and not a rounded lump; the best edge is thus obtained for observation of its texture. In the field, the first test may be made for hardness—a character determined with reasonable accuracy by the facility with which the specimen can be scratched, if at all, by a pocket-knife. The result will show to which of the three main divisions of the following table the rock may be referred—scratched with ease, with difficulty, or not at all. It may then be tested for effervescence by dilute hydrochloric acid—always carried for that

purpose in geological surveying. The fact of its effervescing rapidly, slowly, or not at all, will narrow still more the limits of the list in which it is included. Further determination must then be made by the additional tests of texture, color, &c., in the second column of the table, which in most cases will settle at least the class to which a mineral or a rock belongs. The texture is best observed at the chipped angle of the specimen, and with a pocket lens, if not otherwise apparent. It may be crystalline, glassy, compact, earthy, granular, or laminated—all which characters are obvious if sufficiently pronounced to be visible. The peculiarities of fracture, lustre, and streak are valuable aids in precise examination, but are omitted from the table for the sake of greater simplicity, as without them results may be obtained sufficiently near for all practical purposes. The behavior before the blow-pipe of many substances is given, to distinguish some which cannot otherwise be separated. This instrument is of great assistance in discovering the exact character of rocks and ores; a microscope also is invaluable for the same purpose. There are some which may be chemically analyzed without much trouble; but the works specially devoted to blow-pipe and chemical analysis should be consulted for the methods of accurate determination of the ultimate constituents of a specimen.

TABLES FOR APPROXIMATE DETERMINATION OF THE MORE COMMON MINERALS, ORES AND ROCKS.

1. *Those which are easily scratched by a knife,* and—	*Additional tests, Texture, usual color, behavior before the blow-pipe, &c.*
(*a*) *Effervesce rapidly,* are—	
Calcite (carbonate of lime)	Crystalline, white or tinted, infusible, reduces to quick lime
Satin spar (carbonate of lime)	Fibrous " "
Marble (carbonate, with some silica, alumina) &c.)	Crystalline, various colors
Limestone " "	Compact " "
Chalk " "	Earthy, white or pale yellow
Galena (sulphide of lead)	Crystalline, dark gray color, decrepitates and fuses, yielding metallic globule
(*b*) *Effervesce slowly.*	
Dolomite (carbonate of lime and magnesia)	Crystalline, white or tinted, infusible, reduces to quick lime
Magnesian limestone " " with some silica, alumina, &c.	Compact or granular, grayish color
Chalybite (carbonate of iron)	Crystalline, brownish color, blackens and becomes magnetic
Clay ironstone (impure carbonate of iron)	Concretionary, brown
(*c*) *Do not effervesce.*	
Selenite (sulphate of lime)	Crystalline, white, exfoliates, becomes opaque
Gypsum (sulphate of lime)	Compact or minutely crystalline, white or tinted " "
Fluor spar (fluoride of calcium)	Crystalline, white or purple-tinted, fuses to a clear bead, which on cooling becomes opaque
Graphite (carbon)	Crystalline, foliated black, infusible
Coal (impure carbon)	Compact, black
Hornblende schist	Foliated, black
Glauconite (silicate of iron and potash)	Compact, olive, green, fuses to magnetic glass
Chlorite (silicate of magnesia, alumina and iron)	" foliated or granular, dark olive green, fuses on thin edges with difficulty
Chlorite schist (chlorite, quartz, &c.)	Foliated, green
Mica (silicate of alumina, &c.)	Various colors, plates elastic, fuses on thin edges only
Mica schist (mica, quartz, &c.)	White or green (folio hard and glistening) dark gray
Talc (bisilicate of magnesia)	White or green, plates not elastic, fuses on thin edges with difficulty
Barytes (sulphate of baryta)	Crystalline, white or tinted, decrepitates and fuses with difficulty
Blende (sulphide of zinc)	Crystalline, black or brown, infusible alone
Blue vitriol (sulphate of copper)	Crystalline, with soda yields copper bead
Copper glance (sulphide of copper)	Crystalline, lead gray, fuses yielding copper bead
Copper pyrites (sulphide of copper and iron)	Compact, brass-yellow, fuses yielding magnetic bead
Copperas (sulphate of iron)	Compact, green, fuses with borax yielding a green glass
Steatite, "soapstone"	Compact, whitish, fuses with difficulty
Serpentine rock (silicate of magnesia)	Compact, dark olive-green, fuses on thin edges
Fuller's earth (silicate of alumina)	Earthy, greenish brown fuses to porous slag

Slate " "	Compact (cleaved) dark gray
Rock salt	Crystalline, tinted, decrepitates and fuses
Sandstone, micaceous	Granular or laminated (laminæ, glistening) various colors
2. *Those which are with difficulty scratched by a knife,* and—	
(*a*) *Effervesce rapidly.*	
Calamine (carbonate of zinc)	Compact, grayish, infusible alone, fuses easily in borax
(*b*) *Effervesce slowly.*	
Limestone, siliceous	Compact, various colors
(*c*) *Do not effervesce.*	
Felspar, orthoclase (silicate of alumina and potash)	Cyrstalline, sometimes compact, white, or pink; fuses on thin edges only
Felspar, oligoclase (silicate of alumina and soda)	" " white or tinted, fuses with difficulty to clear glass
Felspar, common	Compact " "
Hornblende (silicate of lime, magnesia, &c.)	Crystalline, green, brown, or black, fuses easily to magnetic globule
Hornblende rock	Compact, green, brown, or black, fuses easily
Augite (silicate of lime, magnesia, &c.)	Crystalline, greenish-black, fuses easily to gray glass
Hypersthene (silicate of magnesia and iron)	Crystalline, brownish-green, fuses easily to black enamel
Hypersthene rock, "greenstone" (oligoclase and hypersthene)	Crystalline, greenish-black, fuses easily
Felsite (orthoclase and quartz)	Compact, gray, weathers white
Dolerite (oligoclase and augite)	Crystalline, grandular, dark gray
Basalt	Compact, black
Diorite, "greenstone" (oligoclase and hornblende)	" green, weathers brown
Porphyrite (oligoclase and hornblende, &c.)	" pink, brown
Gabbro, "greenstone" (oligoclase and dillage)	Crystalline, greenish
Trachyte	Compact (feels rough) gray
Obsidian	Glassy, brown or gray
Phonolite, "clinkstone"	Compact, gray, weathers white
Apatite (phosphate of lime)	" infusible
"Coprolite" "	Concretionary, brown
Specular iron (peroxide of iron)	Crystalline, steel-gray, infusible alone
Hæmatite " "	Reniform, red
Limonite "brown hæmatite"	Compact, brown
3. *Those which cannot be scratched by a knife,* and—	
Do not effervesce.	
Granite (quartz, felspar and mica)	Crystalline
Gneiss (" " in folia)	"
Syenite (felspar and hornblende)	"
Quartz (silica)	" white or tinted, infusible alone
Quartzite (fine grains of quartz in siliceous matrix)	Compact, granular
Quartz sandstone " " (if a slow effervescence the matrix is calcareous)	" "
Flint (silica, not quite pure)	" black or gray
Hornstone	" "
Chert	" various colors
Iron pyrites (bisulphide of iron)	Crystalline, bronze-yellow, fuses to globule attracted by magnet

(2) *Geological Mapping.*—It is very essential in tracing and mapping geological boundaries to have as good a map as possible of the district to be thus surveyed, for, however accurately the lines may be laid down, any errors on the map must affect the after calculations. All the physical features of the district should be distinctly indicated on the map, such as rivers and streams, and heights above the sea level given in figures here and there are of great advantage. Maps drawn to a scale of 1 in. to a mile answer well for general purposes; if great accuracy be required those on a 6 in. scale should be used. Both kinds are issued by the Ordnance Survey; of the whole country on the smaller scale, but on the large scale those of a part only have up to the present time been published. Contour lines, which run through all the points where a horizontal plane at any given height would intersect the surface of the ground, when engraved on the map, are of great assistance in geological surveying. To the eye accustomed to them these lines convey at a glance the physical geography, or the actual shape of a tract of country. Contours, of course, run in a V-like shape up the valleys, in straight lines on even flanks and ridges, and sweep in curves round the outlines of the hills; their variations are numerous as those of the features themselves, but these kinds of form prevail in all.

The three following propositions, if remembered, will afford considerable aid in geological surveying: (*a*) The bound-

ary lines of horizontal strata exactly coincide with the contours. (*b*) The boundary lines of strata dipping towards a hill are less winding than the contours. (*c*) The boundary lines of strata dipping from a hill are more winding than the contours. (*a*) It is evident that if we can once determine a point through which the boundary or other definite line of a horizontal stratum passes, a contour drawn from this point will accurately represent also the geological line. (*b*) If the stratum dips into the higher ground all points at the same level, exactly along the line of strike, must be also on such boundary or other definite line, when its passage through one of them has been ascertained. A line following the curves of the contour, but flattened in proportion to the dip, represents the line required. (*c*) When the stratum dips with the slope of the ground, the line must be discovered at several points, and these points must be united by exaggeration of the contour, with reversal of the windings if the dip exceeds in amount the slope of the surface feature. In practice the ground must, of course, be gone over, and the actual line followed, for dip may change anywhere, and it often does so in places where alteration is least expected. Faults also may occur; these suddenly interrupt the continuity of a boundary and involve a fresh line of their own, representing the broken ends of the strata that have been upheaved on one side of it, or thrown down on the other. A geological map is one which, as we have seen, defines the area occupied by the surface of each formation, or by its denuded edge where it comes to the level of the ground. It follows that to construct such a map with accuracy, every part of the surface within any area to be geologically surveyed must be examined. If by any means the surface of such an area were to be proved by a boring or trial holes, in every acre of ground, and the varying results shown by different colors, a geological map would be roughly presented. But it would be an approximation only, for there would still remain to be shown the exact position of the lines of division between the holes or borings. Similar evidence to that afforded by trial holes may be obtained, in many other ways and with much less trouble, as to what is the uppermost stratum at any given point, or any number of points; and for our present purpose it is in regard to this stratum only that the information is required. Almost every bank where the road is in cutting, and every ditch of even moderate depth, will yield evidence as to the kind of rock at the particular spot where examined. It is obtained by picking into the bank, by spudding at the side of the ditch, or by cutting at the face of every exposed section; but care must be taken to get down to the actual stratum beneath the soil and rain wash. In the absence of ditches, trenches, and banks, we must pick or bore with a spud through the surface-soil here and there on either side of the probable line of boundary we are seeking, look out for the heaps of different stuff thrown out from their holes by moles and rabbits, search in ploughed fields for lumps of the rock we are tracing, and, lastly, we must accustom our eye to judge from the soil itself what is the rock beneath, from which it has been formed by a process of disintegration. Another important point to be noted is the existence of springs, as these indicate not only a change from pervious to impervious strata, but also the actual lines of division. All the results of the examination of the ground must be entered on the map by some mark or symbol, in the exact situation of each observation, and from these the geological lines will be drawn. In surveying a district for the purpose of mapping the outcrop of its strata, it is well to follow the lines of ditch and fence by which it is intersected, as these, although somewhat irregular, serve to guide one in covering all the ground without going twice over any portion. Such lines are occasionally too far apart, but then they must be left, and the intervening spaces walked over, in search of sections and other evidence. By following a line of fence, for, say, half a mile in any direction, and returning by another the width of one field apart from the first, and by repeating the process at the distance of another field, all details concerning a considerable area are collected at the same time. These may involve the drawing of several geological lines as we cross and recross the boundaries of the

strata that occur within the limits of the district thus traversed. But it is frequently found more convenient to commence and follow out one line only at a time; this is done by walking along a ditch or fence until we pass the line, then across the end of the field, and back by the next fence until the line is again crossed, and so on. By the term "boundary line" is meant that which bounds a formation, which describes its lower margin, and in fact indicates its extreme occurrence in any direction. The upper edge of a formation, where it first appears at the surface of the ground, is called its "line of outcrop," and this of course corresponds to the "boundary line" of the one above.

The nature of some of the rocks occurring in any district to be surveyed having been roughly determined, their relation will be worked out, and then occupied by each defined by drawing its boundary in the following manner:—Let it be assumed, for sake of illustration, that the evidence obtained, whether by trial holes or by the preceding methods, will establish the existence of limestones over all the higher ground, of clay upon the flanks of the hills, and of ferruginous sandstone in places along their foot, with clay again in the plain beyond. Starting from some point on the table land, and following a line of fence, the surveyor notices that the soil is light, and full of fragments of whitish limestone, varying in size from small grains to lumps as large as a hen's egg; and in the ditch he occasionally sees the limestones in their undisturbed position. Just below the point where the ground begins to fall he observes, in a slipped portion of the bank, rock of a more sandy nature, full of concretions of ironstone, and near this point is a small spring, the water from which has scooped a hollow and a channel in the blue clay just below. It is evident that the pervious limestones overlie the impervious clay, by which the water that has percolated through them has been thrown out; also that there is a bed of ironstone between, but possibly of slight thickness only. The line of division, of course, passes through this spring, the position of which must be fixed on the map, by compass bearing or otherwise, and a short line drawn in pencil from it to either hand, in the same direction and of the same form as a contour line would have at that elevation. This line of boundary will again be met with in returning by the next fence, although it may not again be exposed by a slip or indicated by a spring; but when the surveyor arrives near the spot through which he expects it to run he seeks for it by picking, spudding, or some other of the methods already described. He may not see the junction of the beds, but he will presently be at a spot where limestones occur just above him and blue clay below, and here, of course, must be the boundary. At this spot is, perhaps, a small plantation—shown on the map. He will draw contour lines from it to either side, one of which lines will unite with that drawn from the first fence in this direction. It is for the present assumed that the beds are horizontal; should it prove otherwise, the pencil lines, if curved, must be flattened or exaggerated, accordingly as the dip is into or away from the hill. But to return to the line of fence along which the mapping was supposed to be commenced. After passing the spring, the surveyor walks for some distance over a clay of bluish color, as seen every few yards in the ditch that runs straight down the hill. The soil is hard, and in many places cracked; it would sufficiently indicate the nature of the stratum beneath, even were this not visible as it is in the sides of the ditch. Towards the lower part of the slope the soil gets lighter, being covered by a sandy wash from the hill above, and presently a pond is met with, which shows, when its margin is picked into, signs of a bed of sandy ironstone. This is noted on the map by a symbol in its exact position, and left for the present; it may be of trifling local occurrence, or it may be part of an important deposit. Beyond this is blue clay again, covered by a foot or two of sandy wash, but exposed wherever a ditch, pond, or other excavation through the surface soil lays it open to inspection. Returning by the second fence in the direction of the high ground, an exactly similar (but reversed) sequence of strata is observed. There is, however, a brickyard situated just at the foot of the slope, in which is seen a bed of calcareous and ferruginous rock, 2 feet thick, evidently continuous—judging by

contour—with that noticed in the pond, and a line is drawn to connect the two points, following the shape of the ground. Continuing his walk up the hill, the surveyor traverses the blue clay until he reaches the small plantation above mentioned, beyond which he sees only limestones in which are several quarries on the table land.

In this way are boundary lines discovered and drawn, they follow the form of the ground, which, indeed, is mainly due to the varying hardness and chang ing dip of the rocks where they rise to the surface. For, precisely in inverse proportion to these conditions, have the agents of denudation worn them away; or to put the point in another form, the prominent minor features of a district are in exact proportion to the power its rocks possess of resisting denudation. As dissimilar rocks must thus make a change of feature along their junction, a knowledge of the fact is, as we have seen, turned to account, and is of great service, in drawing their lines of boundary. It frequently happens that lines have to be drawn through large parks, woods, moors, and marshes, where, perhaps, no evidence whatever can be obtained. In these cases the difficulty may be considerably lessened, by first mapping for a good distance around such obscure areas. With the data and the ideas thereupon thus gained, the lines may then be run by feature alone, with every chance of a near approach to accuracy.

The term "Dip" has frequently been used, and it is scarcely necessary to explain that it means the angle at which the bedding planes of strata are inclined to the horizon. A line passing from any point on the surface of a bed through another point which is the lowest possible at that distance from the first—in other words, the line of greatest steepness, represents the "direction of the dip." It follows that another line at right angles to this must coincide with that portion of the rock which is horizontal, and which would be seen in such a position in the face of a quarry cut back in the dip's direction. This second line is called the "strike" of the rock, and were the surface of the ground a level plane the outcrop of a stratum would always coincide with the strike, and be, throughout its entire length, at right angles to the dip. But as the surface is uneven, the outcrop winds accordingly, crossing and recrossing the general line of strike, which must perforce remain the same until the dip assumes an altered direction. As the amount of dip varies, so does the breadth of ground that a bed of given thickness will occupy at its outcrop. Therefore, when any two of the three following factors are known or can be ascertained, the third can be readily found by diagram or calculation: —(1) Thickness; (2) Dip; (3) Breadth of horizontal outcrop. For measuring a dip, clinometers are generally used, but the kind of instrument is of small consequence so long as it will fairly indicate the amount of inclination. It is most frequently in mines, quarries, brickyards and similar places, that sections of the rock are seen, but it should be remembered that these exposures may not be in the true dip's direction, and that the apparent dip only can thus be taken. This must be observed in two or more faces, making a considerable angle with each other, and the result worked out by the rule given below, or by some other method. The true dip may be greater, but it cannot be less, than that seen in any face of a section open to observation.

Rule.—When two observed dips incline from or towards the angle enclosed by their lines, the true dip is at right angles to a line thus laid down:—Set off from the angle on each one of the two lines of apparent dip, a number of units corresponding to the number of degrees of dip observed along the other line, and connect the two points by a line. This line coincides with the strike, and is consequently at right angles to the true dip's direction. When one observed dip inclines from and the other towards the angle, the problem can be worked out best from a triangle constructed by prolonging one of the lines of apparent dip beyond where it touches the other. Both apparent dips will then run either from or towards the angle thus formed, and the true dip can be found by the above rule. Should the amount of dip be considerable, and great accuracy be required, set off instead of "the number of degrees observed," the tangent of the angle of apparent dip. For, except in the smaller angles, there is an error arising from the difference between their circular measure

and their tangent, but in most cases this is so slight that it may be disregarded.

When the direction of the dip has been worked out, it becomes necessary to ascertain its amount, also from the apparent dip observed in the quarry or elsewhere. From any two observed dips the amount and direction of the true dip may be obtained by calculation, but for all practical purposes the results arrived at in the following manner are sufficiently accurate and much more expeditious.

The dip and its direction may be worked out, and the existence of two different dips, or even of faults, discovered in any locality, where no sections of the bed are exposed. This is done by first accurately surveying the outcrop of some definite line, and by then taking the relative heights of three of the most suitable spots upon it for that purpose. These spots should be so chosen that lines connecting them will make with each other the nearest possible approach to a right angle; the distances apart must be measured or scaled from the map; the heights can be taken by a level, or by an aneroid if extreme accuracy be not required. The points thus selected on the outcrop of a bed, on its under or upper surface if of any thickness, will afford the same information as if the stratum along the line connecting the points were exposed in two faces of a quarry. The lines represent the direction, and the heights will give the rise in the measured distances, that is, the amount, of the two apparent dips, from which the amount and direction of the true dip can be found by the method described. For a description of the instruments used in geological surveying and for tables of dip, depth, and thickness, the reader is referred to the treatise previously mentioned—"Field Geology"—which is intended more especially for geological students, and in which the subject is treated at greater length than is considered necessary in papers designed for those to whom such instruments are necessarily familiar.

THE CONSTRUCTION OF HEAVY ORDNANCE.

By JAMES ATKINSON LONGRIDGE, M. Inst. C. E.

From Proceedings of the Institution of Civil Engineers.

NINETEEN years ago, the Author of the present Paper brought before the Institution of Civil Engineers a communication "On the Construction of Artillery, and other vessels, to Resist great Internal Pressure." The chief object of that Paper was, to direct attention to the principles involved in the construction of guns built up in successive rings, or cylinders; or, what is another form of the same, of an internal tube, or cylinder, strengthened by successive coils of wire, put on with certain definite, though varying, tensions. It was shown mathematically that a cylinder, or gun, could be thus constructed so that its strength would increase directly as its thickness—a result not attainable in any other way, though approximated to by the systems proposed by Mr. Treadwell, Captain Blakely, and Sir William Armstrong, of successive rings, or hoops, shrunk one upon the other. The more numerous the rings, and the less their individual thickness, the greater is the approximation to uniformity of strain; but it was shown that, in order to arrive at satisfactory results, extreme accuracy of workmanship was necessary; so much so that, in the case of an 8-inch gun with four rings, or hoops, an error of $\frac{1}{100}$ inch in the diameter of the outer ring would reduce the strength of the gun about 40 per cent.

Whilst the subject was before the Institution, although some objections were taken as to practical details, the principle itself was never challenged; and, in closing the discussion, Mr. Bidder, the President, said: "It must be admitted, that the theory propounded by Mr. Longridge . . . had been satisfactorily demonstrated. . . . Practical objections had, however, been fairly and legit-

imately urged against the proposed plan. These related chiefly to the difficulty of securing the ends of the wire, of strengthening the breech, and of forming the muzzle. How far the Author (Mr. Longridge) had succeeded in meeting those difficulties the Members must judge. It was, however, evident that he had established such a *prima facie* case as should have entitled him to have received the attention of the Government, in his attempts to produce a light and efficient gun; especially when it was considered, that the subject was only now, for the first time, undergoing that careful scientific investigation to which its great importance entitled it."

The practical objections alluded to were of such a nature that, after the long discussion which had taken place, it was impossible for the Author to take up the time of the Institution in replying to them. They were, moreover, minor points, not involved in the principle under discussion; and although, without exception, they had all been considered and provided for by the Author, he was prevented by lack of time from entering upon them in reply. Since the year 1860 he has given the principle a practical form, and has endeavoured on one or two occasions to induce the Government to make a trial of the same; but, meeting with no success, he has long since given up anything beyond a scientific interest in the question.

Meantime gun-making has gone on. The so-called "Woolwich system" of construction has been adopted by the Government; and no one who has seen Woolwich can fail to admire the practical talent which is there displayed, or the magnificent workmanship resulting therefrom. Neither can it be denied that guns have been constructed vastly more powerful than was generally contemplated in 1860. But, in spite of all this, these very large guns can hardly yet be said to have passed out of the "experimental" region.

The cracking of the inner tube of the 81-ton gun is somewhat ominous, and the more so that it is far from being an exceptional case. Other guns of a smaller caliber have had their inner tubes cracked, and the question naturally arises how far these accidents are attributable to the system of construction. An examination of this question is one of the objects of the present Paper; and, in order to avoid cavil, the Author proposes to direct his observations to the Woolwich system as described officially in a "Treatise on the Construction of Ordnance," prepared in the Royal Gun Factory, and printed by order of the Secretary of State of War, April 1877.

In a former treatise published by the same authority, and corrected up to January 1872, it is stated (page 17) that this system is a "modification of the Armstrong system, and differs from it chiefly in building up a gun with a few double or triple coils instead of several finely-finished single ones." And at page 31 of the later treatise it is said: "This [system] consists of using larger coils made of thicker bars, and so much stronger longitudinally, that the forged breech-piece becomes unnecessary. The greater weight and strength of these outer coils also allows compression to be given more certainly to the steel barrel and inner coils." It will be seen presently how far this last assertion is justifiable.

In the treatise of 1872 (chap. ii., p. 22) there is "an attempt to explain . . . . the science of constructing guns, and to show by reference to modern ordnance how far theory is carried out in actual practice. The Authors—Captain Franc S. Stoney, R.A., and Captain Charles Jones, R.A —both of the Royal Gun Factories—begin by stating the well-known fact, that in a homogeneous cylinder the strength is not proportional to the thickness of metal, and that no possible thickness can enable a cylinder to bear a continual pressure from within greater per square inch than the tensile strength of its material. They proceed to say, that the material of the inner barrel must have sufficient hardness to resist the action of the powder and the friction of the projectile, and that the strain upon the material during explosion decreases as the distance from the inner circumference increases; but that the law, or formula, according to which a gun should be so constructed, that its resistance to the shock of the discharge should be equally distributed throughout its mass, is not exactly known.

This assertion is repeated in the treatise of 1877, page 29.

In both publications mention is made of two formulæ:

1. That of Professor Barlow—

$$\frac{\sigma}{s}=\frac{r^2}{\rho^2};$$

2. That of Dr. Hart, of Trinity College, Dublin—

$$\frac{\sigma}{s}=\frac{r^2}{\rho^2}\times\frac{R^2+\rho^2}{R^2+r^2};$$

where

σ=the tensile strain at the rodius ρ;

s=the tensile strain at the radius r, the inner radius of the gun;

R=the outside radius of the gun;

r=the inside radius of the gun;

ρ=any other radius.

In neither of these treatises is mention made of the formulæ given by the author in his paper read before the Institution in 1860, although the formulæ of Dr. Hart and of Professor Barlow do not afford means to determine the dimensions of the various rings, upon which determination the successful application of this system depends.

In a note to page 23 of the treatise of 1877, referring to the two formulae of Dr. Hart and Professor Barlow, it is said that "the actual tension of each layer probably lies somewhere between the results given by" these two formulae, and that the latter is the simpler, and its results have been shown to be fairly trustworthy in practice. And yet in the same note it is stated that, "in the case of the 10-inch gun [5 inches thick] the tension of the interior compared with that of the exterior would, according to Barlow, be as 100 to 25, or four times as great, but according to Hart, only as 125 to 50, or $2\frac{1}{2}$ times as great." Surely such a discrepancy is serious; and, coupled with the previous assertion, that "the law is not exactly known," the inference is legitimate that, if the Woolwich practice be founded on these formulae, it is wanting in that scientific basis which might be expected in such an establishment as Woolwich. Moreover, even did the two formulae give approximately accordant results (which they do not), they are insufficient for the purpose required. What is wanted is, to determine the strains on a ring when submitted to certain internal and external pressures simultaneously; and farther, when several rings are superimposed, to determine the relative actions of each ring when a given internal pressure is applied to the first and no pressure to the outside of the last. Beyond this, it is necessary to determine the dimensions of the rings before they are put together, so that when put together, and a given internal pressure applied, the whole of the rings may be equally strained; and yet that no strain shall exceed the elastic force of the material.

In neither treatise is any attempt made to solve these problems, nor is any mention made of the complete solution given by the author in the paper above referred to, and contained in detail in the appendix to that paper; and yet, at page 26 of the treatise of 1877, it is said that "Gunmakers . . . can build up a hollow cylinder, the walls of which may be composed of concentric layers of different strength, so that each may arrive at its limit of elasticity at the same time; so that, in fact, when the circumference of the bore reaches its elastic limit and becomes permanently deformed, each successive ring from within outwards is also permanently deformed."

At page 25 of the treatise of 1872 it is stated, that one of the essential principles of Sir William Armstrong's method consists in "shrinking the successive parts together, so that not only is cohesion throughout the mass ensured but the tension may be so regulated that the outer coils shall contribute their fair share to the strength of the gun, in accordance with the theory already explained." But in the next page it is said, that "Sir William Armstrong did not carry out his plan with theoretical precision, but that the coils were simply shrunk together sufficiently to secure the stability of the frabic, and that a small variation was immaterial."

Now, during the discussion on the Author's former Paper, in answer to a question put by him, Sir William Armstrong replied: "The outer layers and rings of metal were not put on with any calculated degree of tension; they were simply applied with a sufficient difference of diameter to secure effective shrinkage."

Again, at page 27, of the treatise of 1877, it is said of Sir William Arm-

strong's method, that the tension is so regulated "that each coil should perform its maximum amount of useful effect in resisting the pressure from within." But this is accompanied by the following foot-note: "Not that it was attempted rigidly to carry out the tension and compression of the several rings in accordance with actual mathematical calculations, but the layers were put on successively, with sufficient shrinkage to ensure a certain amount of compression of the inner portion." In the treatise of 1872 (page 26) it is further stated: "His [Sir William Armstong's] primary object therefore was to secure cohesion throughout the mass, and in doing this within the limits of shrinkage, before stated, he built up his gun to a certain extent in accordance with theory."

From the above extracts it is apparent that, although the advantages of a built-up gun are fully recognized, the endeavor to carry out the idea practically has not yet been made in accordance with scientific accuracy by Sir William Armstrong.

How then does the matter stand at Woolwich? It is mentioned, page 27, treatise of 1872, "That the Woolwich," or, as it is there termed, "Mr. Fraser's plan is an important modification of Sir William Armstrong's, from which it differs principally in building up a gun with a few long double or triple coils, instead of several short single ones and a forged breech-piece. There is less material, less labor, and less fine working, and consequently less expense."

Without doubt the Fraser gun possesses these advantages as compared with the Armstrong gun, but, as will be presently shown, it does not dispense with fine or rather accurate workmanship, and it is not so strong a gun. It is a step backwards—to a great extent an abandonment of the coil principle, and it approaches nearly to a homogeneous gun with a steel lining. The guns constructed on this system up to 1869 were in reality homogeneous wrought-iron guns lined with steel.

It is not denied that a fairly useful gun up to a certain size can be made on this system, and at a moderate cost as compared with Sir William Armstrong's; but, unless properly proportioned, it may easily fail by its inner tube cracking, as the great gun mentioned at pages 18 and 19 of the treatise of 1872, and several others, did. With guns having bores up to 7 or 8 inches in diameter there is no great difficulty in construction, but from 9 inches upwards the case is different. The Author will now proceed to examine more in detail the Woolwich or Fraser system, which, as applied to large guns, will, he thinks, be found both costly and unreliable.

Turning to the treatise of 1872, which is in some respects more explicit than the later treatise of 1877, it is stated, at page 26, with reference to the all-important question, shrinkage, that "in the Armstrong or original construction, a greater proportion of shrinkage was given to the inner layers than the outer, because so much of it was absorbed by compression. The shrinkage, however, never exceeded ·002 inch per inch of diameter." But on the preceding page it is said "the tension on no coil should exceed $\frac{1}{1000}$th of its diameter;" and this is repeated in the treatise of 1877. Yet it is stated in both treatises (page 26 of 1872 and page 28 of 1877) that in "guns of present construction the heavy breech coil compresses the steel barrel to such an extent that the latter becomes in some instances as much as $\frac{1}{100}$th of an inch smaller in diameter during the process of shrinking." Again, it is said (page 26 of 1872); "Much too will depend on the thickness and strength of the coil to be shrunk on; for the heavier it is, the tighter will be its grip, and the more will the inner parts be compressed and supported; whereas a thin weak coil, if shrunk on the same mass, would probably suffer from over tension."

It is difficult to imagine a more complete confusion of ideas than that which pervades this sentence. The thickness, strength and weight of the coil are not what govern the tension. They enter into the formulae for tension—at least the thickness does; but the principal and governing factor is the shrinkage, which, throughout the whole of the treatise, seems to be considered as too indefinite a thing to be practically dealt with. There is no reason why a weak thin coil should suffer from over tension any more than a thick one, but the contrary.

A similar case of confusion occurs in the following paragraph (p. 29) of the

treatise of 1877: "The shrinkage over the seat of the charge is greatest of all, as that part of a gun must be the strongest and firmest, whilst the shrinkage over the muzzle is the least for an opposite reason;" the inference being that strength and shrinkage are convertible terms, whereas they may be the reverse.

Proceeding with the description, at page 48 of the treatise of 1872, it is said: "Shrinking is employed not only as an easy and efficient mode of binding the successive coils of a built-up gun firmly together, but also for regulating as far as possible the tension on the several layers, so that each and all may contribute fairly to the strength of the gun. When two coils or tubes are to be shrunk together, the interior of the outside one, having been fine-bored to that degree of smoothness which is necessary for close contact and mutual support, is gauged to $\frac{1}{1000}$th of an inch every 12 inches of its length. . . To these measurements the shrinkage is added, and a plan made out, according to which the exterior of the inside coil must be fine-turned in order that it may be exactly larger than the bore of the outside coil by the required amount of shrinkage at the respective points."

This is a good description of how a gun ought to be made; but, after it has been repeatedly stated that no definite amount of shrinkage is applied, that the Woolwich authorities have no formulæ for its determination, and that the law by which it should be governed is not even known, all these precautions to ensure accuracy to the $\frac{1}{1000}$th of an inch seem absurd.

Enough has probably been said to prove that the present practice at Woolwich is wanting in scientific precision, and that the results arrived at by the costly experience of that great establishment are based upon empiricism, and can hardly lead to economy, or efficiency of construction.

But it is not sufficient to leave the matter thus. A criticism, however just, is of little value unless it leads to the correction of error. An attempt will therefore be made to prove by calculations how far the actual Woolwich practice is wrong, and to show how the errors there fallen into may be avoided.

To begin with the case of a homogeneous gun:

If R = the external radius of the gun;
ρ = the internal " "
y = any other intermediate radius;
f = the internal pressure in the gun;
t = the tension at y;

the equation for tension is—

$$t = f\left\{\frac{R^2\rho^2 + y^2\rho^2}{(R^2-\rho^2)y^2}\right. = f \times \frac{\rho^2}{y^2} \times \frac{R^2+y^2}{R^2-\rho^2} \quad . (1)$$

Taking the case of a 9-inch homogeneous gun of the following dimensions:—

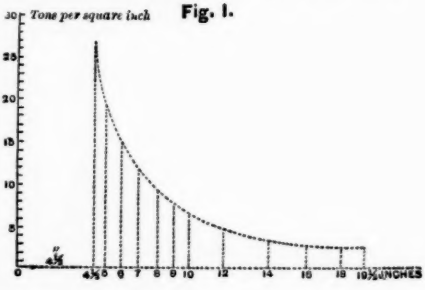
$$R = 19\tfrac{1}{2} \text{ inches};$$
$$\rho = 4\tfrac{1}{2} \quad "$$

and subjected to an internal pressure of 24 tons per square inch, the following are the values of t and y:—

Value of y.	Value of t. Tons per Square Inch.
4.5	26.70
5.0	21.87
6.0	15.60
7.0	11.82
8.0	9.35
9.0	7.48
10.0	6.48
12.0	4.91
14.0	4.96
16.0	3.35
18.0	2.93
19.5	2.62

The ordinates of the following curve show the tensions, the abscissæ denoting the corresponding points in the thickness of the gun. The average tensile strain through the thickness of 15 inches

Fig. 1.



will be found to be 7.2 tons per square inch; and, as the total thickness is 15 inches, the strength of this gun will be 108 tons for each side, or 216 tons

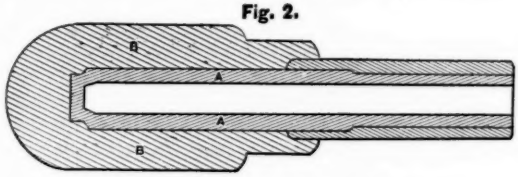
together. Now the internal pressure is 24 tons per square inch, or a diametrical strain of $24\times9=216$ tons, which is of course the same as the resistance; but it is evident that such a gun, if made of wrought iron, must fail by beginning to give way at the inner circumference, which rupture would gradually extend, and the gun would burst.

Proceeding now to the 9-inch Woolwich gun, as built previous to 1869.

Fig. 2 represents the gun, of which the following are the dimensions of the coils:—

9-Inch Muzzle-Loading Woolwich Gun, Mark III.

Fig. 2.



AA Steel tube under the coil	Internal diameter,	9	inches.
	External "	15¼	"
BB Iron coil	Internal "	15¼	"
	External "	39	"

Assumed shrinkage, $\frac{1}{1008}$ of the diameter.
Modulus of elasticity, 18,000 tons for the steel tube.*
Modulus of elasticity, 12,000 tons for the iron coil.
Internal pressure of powder gas, 24 tons per square inch.

The fundamental formulæ for tension are as follows, using the following notation:

T_n = tension at inner surface of nth ring from center.

τ_n = tension at outer surface of nth ring from center.

f_n = internal normal pressure of nth ring from center.

f_{n+1} = external normal pressure of nth ring from center.

R_n = external radius of pressure of nth ring from center.

ρ_n = internal radius of pressure of nth ring from center.

Tension at inner surface

$$T_n=\frac{f_n(R^2_n+\rho^2_n)-2f_{n+1}R^2_n}{R^2_n-\rho^2_n} \quad \ldots\ (a)$$

Tension at outer surface

$$\tau_n=\frac{2f_n\rho^2_n-f_{n+1}(R^2_n+\rho^2_n)}{R^2_n-\rho^2_n} \quad \ldots\ (b)$$

In the present case there are two rings, viz., the steel tube and the iron coil.

Hence result the following equations:

$$T_1=\frac{f_1(R_1^2+\rho_1^2)-2f_2R_1^2}{R_1^2-\rho_1^2} \quad \ldots\ (c)$$

$$T_2=\frac{f_2(R_2^2+\rho_2^2)-2f_3R_2^2}{R_2^2-\rho_2^2} \quad \ldots\ (d)$$

and

$$\tau_1=\frac{2f_1\rho_1^2-f_2(R_1^2+\rho_1^2)}{R_1^2-\rho_1^2} \quad \ldots\ (e)$$

$$\tau_2=\frac{2f_2\rho_2^2-f_3(R_2^2+\rho_2^2)}{R_2^2-\rho_2^2} \quad \ldots\ (f)$$

But, since the two rings are in contact,

let K = the modulus of elasticity of the iron coil

K_1 = the modulus of elasticity of the steel tube;

therefore

$$R_1+\frac{\tau_1R_1}{K_1}=\rho_2+\frac{T_2\rho_2}{K} \quad \ldots\ (g)$$

And since during explosion

$f_1=24$ tons, $f_3=0$.
$\rho_1=4.5$ inches, $R_1=\rho_2\times1.001=7.632625$.
$\rho_2=7.625$ " $R_2=19.5$, $K=12{,}000$ tons,
$K_1=18{,}000$ tons.

From equation (c)

$$T_1=49.6-3.07f_2;$$

and from equation (d)

$$T_2=1.36f_2;$$

* The value here assumed for steel is only an assumption. Important as this element is, little is known about it as affected by tempering in oil.

also from equation (e)

$$\tau_1 = 25.6 - 2.066 f_2;$$

and from equation (f)

$$\tau_2 = 0.36 f_2;$$

also from (g)

$$\tau_1 = 1.49,\ T_2 - 18.$$

There are therefore five equations, from which are obtained the following values:

$T_1 = 16.97$ tons per square inch;
$T_2 = 14.45$ " " "
$\tau_1 = 3.64$ " " "
$\tau_2 = 3.83$ " " "

These are the tensions during explosion, with an internal pressure of 24 tons per square inch.

To find the state of tension before explosion, following the method indicated by the Author in 1860, these values are obtained:

Tons per sq. in.
$T_1 = -13.42$ } The negative sign de-
$T_2 = -\ 9.04$ } noting compression.
$\tau_1 = 5.96$
$\tau_2 = 1.55$

Table 1 represents the conditions of this gun.

TABLE 1.

	Before explosion.	During explosion.
Steel Tube.		
Tension of the interior surface	−13.42	+16.97
" " exterior "	− 9.04	+ 3.64
Iron Coil.		
Tension of the interior surface	+ 5.96	+14.45
" " exterior "	+ 1 55	+ 3.83

Supposing all things to remain the same except the shrinkage, and repeating the calculations, Table 2 shows the strains with a shrinkage of $\frac{1}{2000}$, $\frac{1}{1000}$ and $\frac{1}{2000}$ of the diameter respectively:

TABLE 2.

Tensions of the Tube and Coil of the 9-inch Gun.			Mark III.		
Modulus of Elasticity, Steel 18,000 tons. " " " Iron 12,000 "			Shrinkage.		
			$\frac{1}{2000}$.	$\frac{1}{1000}$.	$\frac{1}{500}$.
			Tons per Square Inch.	Tons per Square Inch.	Tons per Square Inch.
Before firing.	Steel Tube	Inner surface	− 6.71	− 13.42	− 26.84
		Outer "	− 4.52	− 9.04	− 18.16
	Iron Coil	Inner surface	2.98	5.96	11.92
		Outer "	0.71	1.55	3.10
During explosion.	Steel Tube	Inner surface	23.70	16.97	3.60
		Outer "	8.20	3.64	− 5.30
	Iron Coil	Inner surface	11 47	14.45	20.40
		Outer "	3.04	3.83	5.40

N. B.—Internal pressure during explosion = 24 tons per square inch. The negative sign denotes compression.

It is to be remarked that the effect of shrinkage depends upon the value of the moduli of elasticity of the materials used. To exemplify this, Table three shows the strains on the same gun, taking the modulus of elasticity as 12,700 tons for iron, and 13,330 tons for steel, the shrinkage being in both cases $\frac{1}{1000}$ of the diameter.

From this it appears that the effect of increasing the modulus of elasticity is to increase the initial compression of the steel tube and the tension of the outer ring before explosion, whilst during explosion it increases the tension of the steel tube and considerably diminishes the tension of the outer ring.

TABLE 3.

Tensions of Tube and Coil of 9-inch Gun, Mark III. Shrinkage $\frac{1}{1000}$ of the Diameter.			Module of Elasticity. Iron, 12,000. Steel, 18,000.	Module of Elasticity. Iron, 12,700. Steel, 13,300.
			Tons per Sq. Inch.	Tons per Sq. Inch.
Before firing.	Steel Tube	Inner surface..	—13.42	—11.70
		Outer " ..	— 9.04	— 7.86
	Iron Coil	Inner surface..	5.96	5 19
		Outer " ..	1.55	1.38
During explosion.	Steel Tube	Inner surface..	16.97	15.53
		Outer " ..	3.64	2.67
	Iron Coil	Inner surface..	14.45	15.09
		Outer " ..	3.83	4.00

N.B.—Internal pressure during explosion = 24 tons per square inch. The negative sign denotes compression.

From Table 2 it appears that the effect of increasing the shrinkage is, before firing, to increase the compression of the steel tube and the tension of the iron coil nearly in proportion to the increase of shrinkage; and, during explosion, very largely to diminish the tension of the steel tube, but also largely to increase the tension of the iron coil.

Having thus shown the effect of varying the shrinkage and the moduli of elasticity, the effect of firing on this gun may be examined on the hypothesis that the shrinkage is $\frac{1}{1000}$ of the diameter, and the moduli of elasticity 12,700 tons for iron, and 13,330 tons for steel, which are believed to be the approximate values of the material as used at Woolwich.

As regards the steel tube, it appears that the inner surface is exposed to a sudden change from —11.70 to + 15.83, or a range of 27.53 tons per square inch. Now it is generally admitted that a sudden change is equivalent in effect to double the amount of a steady strain, so that in the present case the effect would be equal to a steady strain of 55.06 tons per square inch.

The elastic limit of crucible steel used for guns is about 15 tons per square inch;* consequently the steel tube is (on the double strain hypothesis) actually strained to upwards of $3\frac{1}{2}$ times its elastic force by the explosion. Taking the iron coil, it is seen from the table that the strain is raised from 5.19 to 15.09 tons, or a sudden change of 9.90 tons, equivalent in effect to a steady strain of 19.80 tons per square inch, which, added to the initial strain of 5.19, is equal in effect to a strain of 25 tons per square inch. This is rather above the breaking strain of the material, and therefore it is clear that if the law of a sudden strain—being equal to double that of a steady strain—be true, the inner surface of the iron coil must be ruptured by the first firing.† As, however, it may be argued that there is no certainty about the relative effect of sudden and steady strains, the effect of the calculated strains simply will now be considered. From Table 3 it appears that during explosion the actual strain of the inner surface of the iron coil is 15.09 tons per square inch. Now the elastic limit of the material does not exceed 10 tons per square inch, consequently there is an excess of strain of 5 tons per square inch. The permanent set of the material is about 0.00001 of the length per $\frac{1}{1000}$ ton of excess strain, consequently the inner radius ρ_2 becomes $\rho_2 \times 1.00005$, and the values of ρ_2 become—

before first firing, 7.625;
after first firing . . 7.62538125;

so that the shrinkage after the first firing is no longer 0.007625, but only 0.007245, and the values of $\frac{\rho_2}{R} = \frac{1}{1.00093}$.

By solving the equations of tension with their new values, the following are obtained:

$T_1 = 16.26$ tons per square inch;
$\tau_1 = 3.17$ " "
$T_2 = 14.77$ " "
$\tau_2 = 3.91$ " "

Thus by the first firing the tension on the steel tube is increased from 15.23 tons to 16.26 tons, or $1\frac{1}{4}$ ton above its elastic force; and a further permanent

* *Vide* Experiments on steel and iron, "Report by a Committee of Civil Engineers," 1870.

† Mr. Kirkaldy ("Experiments in Wrought Iron and Steel," 1863, page 83) states, as the result of his own experiments, that the effect on iron of a suddenly applied strain is equivalent to a steady pull about 18½ per cent. greater. This ratio, however, will no doubt depend greatly upon the material under trial.—J. A. L.

set is caused by the second firing, due to an excess strain of 4.77 tons above the elastic limit of the iron coil.

Repeating the calculations with the new values thus obtained, it will be found that the tensions at the third firing are

$$T_1 = 16.60$$
$$\tau_1 = 3.49$$
$$T_2 = 14.62$$
$$\tau_2 = 3.87.$$

Thus each successive firing results in a decrease of the shrinkage, and an increase in the tension of the steel tube; and the inquiry therefore arises what will be the consequence when, by repeated firing, the shrinkage is reduced to zero?

In this case $\frac{\rho^2}{R_2} = 1$, and by solving the resulting new equations the tensions are found to be

$T_1 = 27.2$ tons per square inch;
$\tau_1 = 10.5$ " "
$T_2 = 9.94$ " "
$\tau_2 = 2.63$ " "

In this condition of the gun, let it be required to ascertain the distribution of the strains between the steel tube and the iron jacket.

The equation for this purpose is

$$t = \frac{f_1\rho^2 - f_2R^2}{R^2 - \rho^2} + \frac{(f_1 - f_2)R^2\rho^2}{(R^2 - \rho^2)y^2}.$$

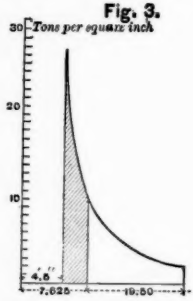
By making $f_1 = 24$, $f_2 = 7.30$,* and the following values of tensions for corresponding values of y (the distance from the center of the bore) will be obtained.

Steel Tube.		Iron Coil.	
y.	t.	y.	t.
Inches.	Tons.	Inches.	Tons.
4.5	27.20	7.6325	10.50
5.0	22.33	8.00	9.10
6.0	16.01	10.00	6.34
7.0	12.20	12 00	4.80
7.625	10.50	14.00	3.83
—	—	16 00	3.26
—	—	18.00	2.86
—	—	19.50	2.63

The state of the gun during explosion is represented by Fig. 3, where the ordinates denote pressures at the distances of the abscissæ from the center of the bore.

*This value is found from the general equation (f).

Fig. 3.



By taking the area of this curve, the resistance of the gun is found to be—

	Tons.
For the steel tube.....	52
For the iron jacket.....	56
	108

Corresponding with the internal pressure on the half diameter, or $4\frac{1}{2} \times 24 = 108$ tons. Thus nearly one-half of the strain is thrown on the steel tube of $3\frac{5}{8}$ inches thickness, which is doing nearly as much work as the 12 inches thickness of iron. The steel tube is, moreover, strained to upwards of 27 tons per square inch, or about 12 tons beyond its elastic limit. The consequence is that permanent set takes place, increasing with each firing, and in time the gun fails by the cracking of the inner tube. Such is the inevitable result of a gun of the above dimensions, built with the regulation shrinkage, if there be such a thing, of $\frac{1}{100}$ of the diameter. It might easily be shown how such a state of things would be aggravated by other conditions of shrinkage, or by variations in the moduli of elasticity of the material, of which no account appears to be taken at Woolwich; but enough has probably been said to show how unscientific is the present practice, and to make it obvious that the cracking of the steel tubes of the Woolwich guns is only a question of time.

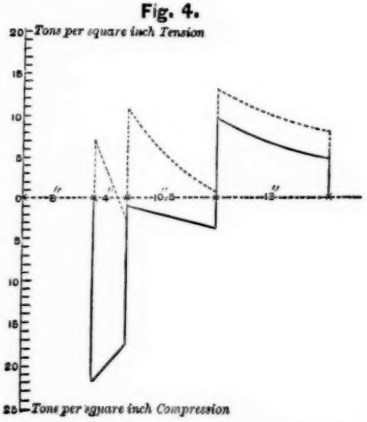
Without doubt a better result might be arrived at by altering the initial shrinkage; but the author believes that a safe 9-inch gun cannot be made on the Woolwich dimensions. To make a safe gun, it is necessary that no portion of it shall, under any circumstances, be strained so as to acquire a permanent set; and

if the idea be correct that a sudden strain is equivalent in effect to double the steady strain, it follows that no gun should ever be strained beyond 5 tons per square inch for iron, and 7½ tons for steel; and this it is not possible to accomplish in a 9-inch gun with an internal pressure of 24 tons per square inch, constructed on the Woolwich system and dimensions, with one or two thick coils.

It may be said that it is unfair to go back to a construction of 1869. The inquiry will, therefore, be extended to the latest Woolwich gun, the 81-ton gun of the present day, assuming it to be bored out to 16 inches diameter. In the absence of exact information regarding the moduli of elasticity,* calculations have been made on two hypotheses: first, that the moduli of elasticity were for iron 12,000, and for steel 24,000; and second, for iron 12,700, and for steel 13,330. The shrinkrage has been taken, in both cases, at $\frac{1}{1000}$ of the diameter, and the inter nal pressure during explosion, in both cases, at 24 tons per square inch.

The condition of the gun before firing and during explosion is shown in Table 4, and Figs. 4 and 5.

Fig. 4.



In both cases the tension of the inner surface of the outer ring is strained beyond its elastic limit during explosion by the simple strain. What must it be then if the suddenness of the strain increases the effect two-fold? The result indicated in the case of the 9-inch gun will inevitably follow, leading eventually to the cracking of the inner or steel tube.

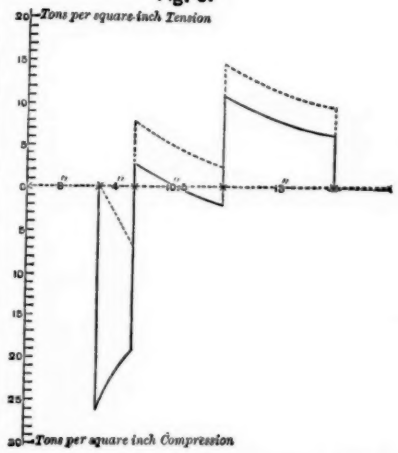
* This observation refers to steel tempered in oil.—J. A. L.

TABLE 4.

Tensions of 80-ton Gun.			Modulus of Elasticity. Iron, 12,000. Steel, 24,000.	Modulus of Elasticity. Iron, 12,700. Steel, 13,330.
			Tons per Sq. inch.	Tons per Sq. Inch.
Before firing.	Steel Tube	Inner surface..	—28.08	—20.55
		Outer " ..	—19.87	—14.45
	First Ring	Inner surface..	2.05	— 1.40
		Outer " ..	— 1.61	— 2.67
	Sec'nd Ring	Inner surface..	10.37	9.89
		Outer " ..	5.81	5.55
During explosion.	Steel Tube	Inner surface..	0.04	6.76
		Outer " ..	— 6.66	—1.94
	First Ring	Inner surface..	7.69	11.30
		Outer " ..	2.43	1.57
	Sec'nd Ring	Inner surface..	14.43	13.56
		Outer " ..	8.10	7.62

N.B.—Internal pressure 24 tons per square inch. The negative sign denotes compression.

Fig. 5.



Figs. 4 and 5 represent graphically the conditions of this gun as shown by Table 4.

In both cases it is apparent that the

uniform shrinkage of $\frac{1}{1000}$ of the diameter is unsuited to the dimensions of the tube and rings, and that a gun so constructed within the limits of the moduli of elasticity assumed must inevitably fail by cracking the inner steel tube. It is, however, possible to construct a gun of 16-inches bore, with a steel tube and two iron coils in rings, as in the 81-ton gun, which shall resist an internal pressure of 24 tons per square inch, whilst, at the same time, no part of the gun shall be strained beyond 10 tons per square inch.

The process of calculation is too long to be given here, but the following are the results:

	Inches.
Inner radius of the steel tubes.....	8.0000
Outer " " " "	14.3902
Inner " " first iron ring.....	14.3770
Outer " " " "	26.6065
Inner " " second iron ring..	26.5900
Outer " " " " " ..	42.5410

The following is a comparison of these dimensions with those of Woolwich 81-ton gun:

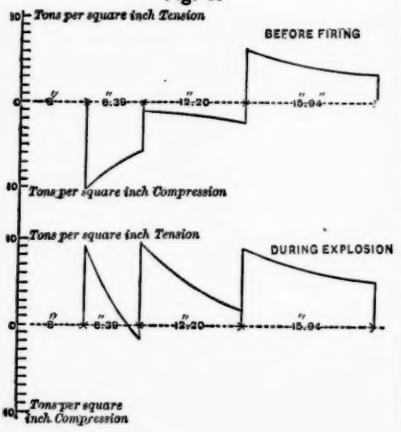
	Proposed Gun. Inches.	Woolwich Gun. Inches.
Internal radius of steel tubes.	8.0000	8.0000
External " " "	14.3900	12.0000
External " gun.....	42.5400	36.0000

The moduli of elasticity in the proposed gun are assumed,

	Tons.
For steel.....	13.330
For iron	12.700

Fig. 6 shows the conditions of the

Fig. 6.



tube and rings of the proposed gun before firing and during explosion.

By calculating, from the formulae above given, the strains borne during explosion for each ring, the following results are obtained:

	Tons.
Steel tube... ....resistance to rupture.	16.18
First iron ring.... " "	59.71
Second iron ring.. " "	116.05
Total.....	191.94

Now the internal pressure on each side of the gun is $8 \times 24 = 192$ tons, agreeing exactly with the calculated strains.

Taking again the strains before firing, the following results are obtained:

	Tons.
Compression of the steel tube....49.54	
" " first iron ring.17.97	
	67.51
Tension of the second ring.....	67.51

Showing the perfect consistency of the results of the formulae throughout.

In the case of the proposed gun, it will be seen that the shrinkage is not the same between the steel tube and the first iron ring as it is between the first and second iron rings, the proportions of the respective radii being—

$$R_2 = 1.00062\rho_2$$
and
$$R_1 = 1.0009176\rho_2$$

In fact each successive pair of rings must have a definite shrinkage of their own, which is altogether at variance with the Woolwich practice.

In the late trial "Thomas *v.* Queen" it was given in evidence by Major-General Younghusband, C.B., R.A., that the Woolwich rule for all guns from 7 inches to 16 inches caliber was $\frac{\text{thickness}}{\text{caliber.}} = 1.75$. In the gun of the same caliber, above proposed by the Author, it would be 2.15 times the caliber; and it may be easily shown from the formulae that the ratio is not a constant, but varies according to the number of rings employed, and to other circumstances. It may be stated generally that the construction of guns upon fixed ratios, whether those of thickness or of shrinkage, is contrary to scientific principles, and can only lead to costly experiments ending in eventual failure.

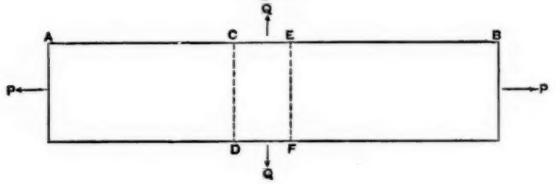
The investigation hitherto has been confined to the circumferential strains caused by the explosion. There is, however, another strain which must not be lost sight of. This is the longitudinal strain on the chase of the gun between the breech and the trunnions, due to a force equal to the products of the area of the gun and the internal pressure. This force is absorbed, partly by the mass of the gun, and partly by the mass of the gun carriage and the resistance of the compressors. In all guns hitherto constructed, the latter portion and the greater part of the former is transmitted to the trunnions through the body of the gun.

In the case of the 81-ton gun the force is 4,824 tons; and, supposing two-thirds of this force to be transmitted through the outer coil to the trunnions, there will be a strain of 3,216 tons on a sectional area of 2,481 square inches, or 1.3 ton per square inch, if the strain be equally distributed through the section.

As, however, the strain is transmitted chiefly from the surface of the inner circumference, it will probably be not far wide of the mark to assume a tensile strain of 3 tons per square inch at that part of the structure.

The question then arises as to what is the effect of this strain of three tons per square inch, combined with the other strains at right angles to it, amounting, as shown in Table 4, to 13½ or 14½ tons per square inch? It will scarcely be maintained that any material can sustain at the same time two distinct strains in different directions, either of which taken separately would bring it to the verge of rupture.

Fig. 7.



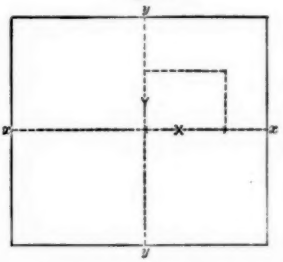
Suppose a bar of iron A B to be strained to the utmost of its resisting force in the direction P, each particle in the section C D is on the verge of parting from the corresponding particle E F. If now at this instant the forces Q are applied tending to lengthen the distance C D and to shorten the distance C E, it is evident that fracture will result.

What is true of ultimate fracture is also true of the elastic limit.

If then two sets of forces are applied to a piece of metal in directions at right angles to each other, as in $x\ x$ and $y\ y$, and if one of these be $= x$ and the other to Y, the joint effect will be in the direction of the resultant, or $\sqrt{X^2 \times Y^2}$.

Applying this to the case of the 81-ton gun, it appears that the strain will be $\sqrt{14^2+3^2}=14.32$ tons, from which it may be assumed that the longitudinal strain has comparatively little effect. It may, however, be asked, whether there is not a danger of the tubes slipping over each other from the force of the recoil? It

Fig. 8.



may be shown by the formulæ that the normal pressure between two coils is

$$f_3 = T_3 \frac{R_3^2 - \rho_3^2}{R_3^2 + \rho_3^2 - 2f_4 R_3^2};$$

and in the case of the outside ring

$$f_4 = 0,$$
$$T_3 = 14,$$
$$R_3 = 36,\ \rho_3 = 22.5;$$

whence $f_3 = 14 \times \frac{790}{1802} = 6.135$ tons per square inch.

Taking a charge of 360 lbs. of pebble powder spaced to 30 cubic inches to the lb., the space occupied by the cartridge would be 10,800 cubic inches; and adding to this a length of six inches of the bore, at which point of the progress of the shot the maximum pressure is reached, the total volume is 12,006 cubic inches filled with the powder gas at a pressure of 24 tons per square inch. This gives a length of bore of about 60 inches expanded to the maximum pressure; consequently the inner surface of the outer tube is under a pressure of $22.5 \times \pi \times 60 \times 6.135 = 27{,}017$ tons. If the coefficient of friction be taken at $\frac{1}{6}$, the force necessary to produce motion must exceed 4,336 tons; and as the actual strain does not exceed 3,216 tons, there is a good margin irrespective of the half-lapping of the coils just in front of the trunnions. There is therefore no danger of the coils slipping in the jacket. Should, however, the coils acquire a permanent set the case would be different, and but for the half-lapping the coils might be displaced.

The result of the preceding investigation shows that, although heavy ordinance may be successfully constructed on the system of a steel tube fortified by two or three thick coils of iron, yet the success depends upon an accurate knowledge of the elasticities of the metal, and a careful application of a reliable formula, neither of which appears to enter into the Woolwich practice. It is therefore not surprising that the Woolwich guns fail by cracking the inner tube; and although they may for a time resist the force of the explosion, the ultimate result must be failure.

The argument constantly used from what is termed the endurance of a gun under a long-continued series of firings is a fallacious one. In a previous discussion at the Institution, Captain Simpson, U. S. Navy, had stated that, "as a proof of the sufficient strength of the metal proposed (cast iron) references was made to firing with a 68-pounder, the gun actually not bursting until tested with a charge of 7½ lbs. of powder and a projectile of 450 lbs. weight, having previously fired a succession of series of 10 rounds each with projectiles of 90 lbs., 135 lbs., 180 lbs., 225 lbs., 270 lbs., 315 lbs., 369 lbs., and 405 lbs. With such a specimen of endurance of cast iron, the Author had a right to confidence in that material."

Now, apart from the consideration that the weight of the projectile (the charge remaining the same) has comparatively little influence on the internal pressure, the probability is that from the very first firing the iron surface began to give way, and that the strength went on decreasing until the final round, when the gun went to pieces. Nothing can be more certain than that as soon as the tension of the inner surface exceeds the elastic limit of the material the gun must eventually burst; the final catastrophe is only a question of time. This applies to every description of gun; hence the necessity of an exact knowledge of the nature of the material, and of a formula whereby the proper dimensions may be determined.

Other important questions arise, viz., as to the construction, and the time occupied in turning heavy guns out of the workshop.

Accurate information on the former of these heads it is perhaps impossible to obtain, mixed up as the cost has hitherto been with the large outlay of capital necessary on each successive increase in dimensions of the gun. It is said, in the treatise of 1872, p. 25, that the cost of constructing guns of the original type is £100 per ton, and of Fraser or Woolwich guns £65 per ton. On the other hand, it has been publicly stated that the cost of the Armstrong 100-ton gun is £16,000, or £160 per ton, and of the 81-ton gun £8,000, or nearly £100 per ton.

Judging from the past, twelve months would be a moderate time for the construction of one of these guns, though by an increase of machinery, plant, &c., no doubt several guns could be manufactured in the same time; but any increase in size will probably necessitate new machinery; and were a gun of 150 tons to be put in hand at Woolwich, it is not likely that it could be turned out within eighteen months from the date of commencement.

The question is therefore of importance, whether any other system of construction would lead to a greater economy of time and money, and, if so, to what extent.

Believing that the principle of construction pointed out by the Author, in

his Paper of 1860, would lead to such economy, it will now be shown how such system may be practically applied to the construction of heavy guns, whether muzzle or breech loaders. It being admitted that the efficiency of the built-up, or hoop system, approaches nearer to theoretical perfection as the thickness of each hoop decreases, it is evident that the method of coiling wire round a central tube, each successive coil having its proper initial tension, affords an easy and practical mode of construction, and at the same time enables the material of every portion of the structure to be thoroughly tested, and applied with its own appropriate strain.

So far there can be no dispute, the circumferential strain can be met by a structure which is practically of uniform strength, so that for any internal pressure one square inch at the external circumference of the gun shall be strained exactly to the same extent as at the internal. Thus the strength of a gun can be increased to any required extent by a simple increase of its thickness, and the strain in every portion reduced below its elastic limit.

The longitudinal strain can be provided for by material independent of the chase of the gun, so that this latter has no work to do beyond resisting the circumferential of bursting strain.

There are various methods of accomplishing this, of which the following types are illustrated by diagrams.

HEAVY MUZZLE-LOADING GUN.

First type.—Gun recoiling on its Carriage.

The gun (Fig. 9)consists of an inner tube, A A, round which coils of wire B B, are wound, decreasing in number and tension from the powder chamber to the muzzle. The tube is open at both ends, but the breech is closed by a plug, C, fitted with a gas check. This, which forms virtually the chase of the gun, and which is of such strength that no portion of it can be strained beyond its elastic limit, is encased in a cast-iron shell made in two parts, D D and E E, firmly held together by wrought-iron bolts, F F, or by other methods. The breech plug butts against the heavy casting, E E, which is furnished with trunnions, G G. To these trunnions rollers, H H, are fitted, so that when the gun recoils the rollers carry the breech backwards along the carriage, I I I, which is inclined upwards at the back.

The chase is supported upon a roller, K, which is raised or lowered by hydraulic pressure. Thus there is no longitudinal strain on the chase of the gun, except what is due to the action of the bolts, F F, which draw back the outer covering of the chase, the inner shell and wire coils being altogether free from tensile strain. The recoil is taken up by the inertia of the heavy mass behind the breech plug, and by the force of gravity on the ascending planes of the carriage, aided, if required, by compressors.

The carriage is mounted turn-tablewise, and revolves round a center pivot, so that the gun can be trained in any direction.

Second type.—Muzzle-loading Gun mounted on ordinary Gun-carriage.

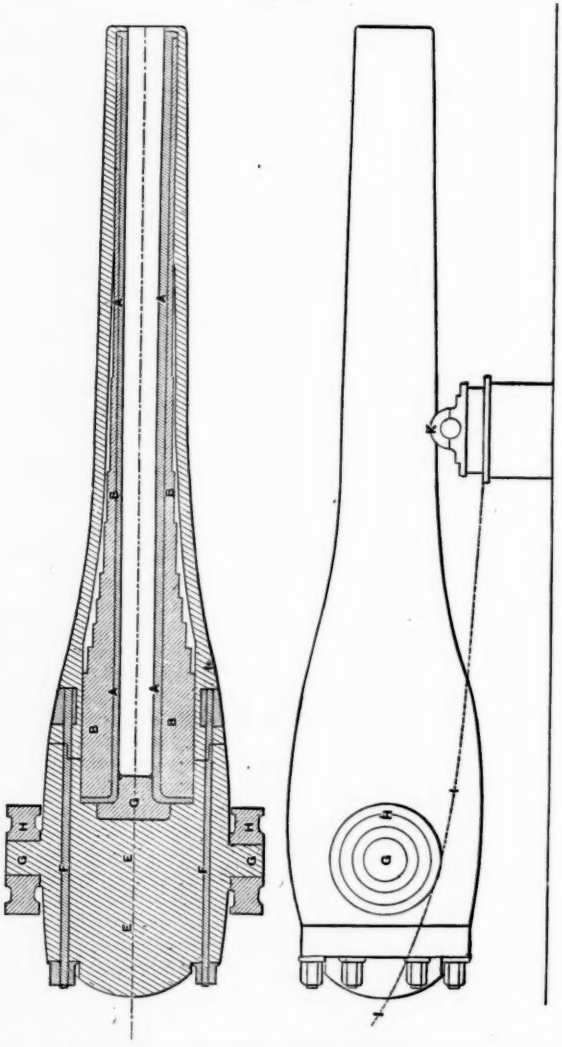
Here (Fig. 10) the main trunnions are behind the breech as in the first type; but instead of being fitted with rollers they are connected by side rods with the cariage trunnions. Thus again the longitudinal strain from the recoil is taken up by material quite independent of the chase of the gun.

BREECH-LOADING GUN.

In these guns (Fig. 11) the breech plug is fixed to a massive block, A A, arranged to slide backwards or forwards along the side rods, B B. Through this block passes a heavy eccentric shaft, C, which terminates on each side of the rods B B. When the eccentric is in its forward position, the sliding block comes up to the breech end, the plug enters into the chase, and being fitted with a proper gas check, all escape of the gases of the explosion is prevented.

On the side rods are forged the carriage trunnions, D, and on their prolongations are forged the eyes, which receive the trunnions of the chase E. These are placed at such a distance from the end of the chase that when the gun is unloaded, as after firing, and the sliding breech-block drawn back by reversing the eccentric, the chase of the gun turns on its proper trunnions, and the breech tips up, so that the bore clears

FIG. 9.

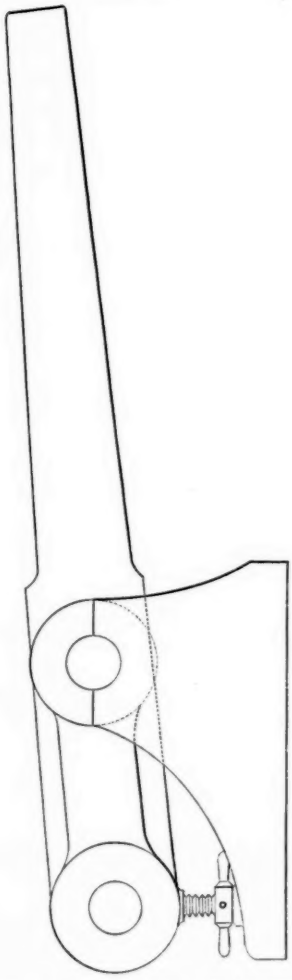


the sliding block and permits the introduction of the projectile and cartridge. The weight of these restores the preponderance to the breech end, which falls back into position, the eccentric is reversed, the breech closed, and the gun ready for firing.

Here, too, it will be seen that the chase is free from all longitudinal strain, which is transmitted from the breech-block to the carriage trunnions by the side rods.

In this system of construction there is obviously no practical limit to the size of the gun. Whatever be the caliber, it can be strengthened by the wire coils to any requisite degree, and the side rods and trunnions may be made of any strength needful. All the strains are direct, the requisite strengths are obtained by cal-

Fig. 10.



culations, and every part of the gun is made without difficulty.

The only practical objection raised during the discussion at the Institution of Civil Engineers in 1860, namely, that of preventing the breech blowing off the chase is effectually provided against, and the whole course of construction is simple and inexpensive.

Whilst for that portion of the structure which has to resist strains the highest quality of material is used, and every portion of it tested before use; for other portions, where mere dead weight is wanted, the very cheap material cast iron is applicable.

No careful measurement to the $\frac{1}{1000}$ inch is required; no inaccuracy of shrinkage is possible; no latent flaw of the material is to be dreaded. Each wire, as it goes into the structure, is tested, and takes its place under the proper tension, actually applied directly as the wire is coiled on.

Again, the side rods when present may be thoroughly tested before use; and the strains to which they are subjected being direct tensile strains, no possible error can arise.

It is especially as regards breech-loaders of large size that this system is applicable. The loading becomes an operation of the simplest nature, performed by men under cover; the breech apparatus cannot blow out or burst. There is no escape of gas from the breech, and the gun can be fired by a simple detonating arrangement, which precludes the possibility of any rush of gas from the vent, and the attendant wear of vents due to that cause.

A small gun, constructed on this system by the Author, was repeatedly fired with heavy charges of powder and heavy projectiles, whilst a cambric handkerchief laid over the breech was not soiled.

The cost of this system of construction will now be compared with the Woolwich system. For this purpose take a 13-inch breech-loading gun, shown in Fig. 10. The length of the gun would be 22 calibers, or 24 feet from breech plug to muzzle. The weight is 45½ tons.

The cost of this gun would be—

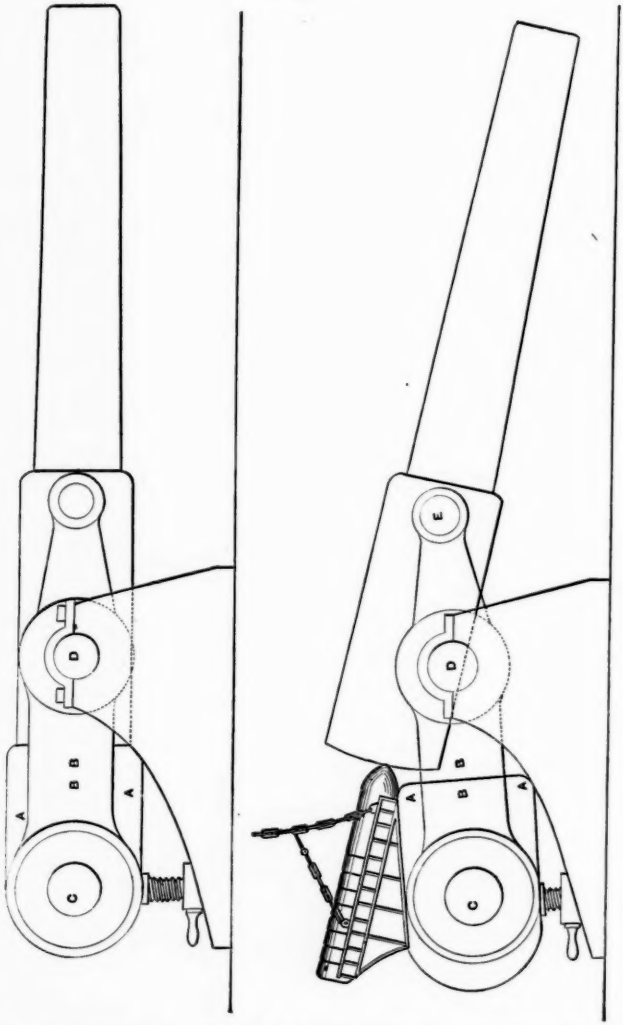
	Tons.		£		£
Wrought iron	17	at	30	=	510
Cast iron	10	"	7	=	70
Steel tube	3	"	80	=	240
Breech plug	½	"	46	=	23
Steel wire	15	"	100	=	1,500
					£2,343

or about £51 per ton.

In the next place, take a 20-inch muzzle-loading gun of Type 1, that is, one recoiling on the carriage.

This gun would be 30 feet long in the chase, and would weigh 150 tons, and it would throw a solid shot of 3,000 lbs. weight with a muzzle velocity of 1,600 feet per second.

FIG. 11.



Its cost, and the material used in its construction, would be—

	Tons.		£		£
Wrought iron	10	at	20	=	200
Cast iron	96½	"	8	=	772
Steel tube	10	"	80	=	800
Breech plug	1½	"	46	=	69
Steel wire	32	"	100	=	3,200
					£5,041

or £33 16*s.* per ton.

In neither case would the material be strained up to its elastic limit.

The calculations of cost have been made on the assumption that the inner tubes of these guns are of steel, according to the Woolwich practice. It is, however, believed that there is no necessity for this expensive material, but that an inner tube of hard and probably of

chilled cast iron, would be as durable, if not more so, than steel.

The function of the inner tube is simply that of transmission of force. It has little or nothing to do with resisting the explosion. In fact, the wire may be so arranged that the inner tube is never in a state of tension.

It may be thought that cast iron would be shattered under the concussion of the explosion. The contrary has been proved, not only by the experimental cylinders described by the Author in 1860, but by a 3-inch breech-loading gun since made, which has resisted repeated firing of heavy charges, although the inner tube of cast iron is only ½ inch thick.

Should the Author's opinion of cast iron prove correct, the cost of guns built on the proposed system would be still further reduced, and the total cost of a 150-ton gun would probably not exceed £4,500, or £30 per ton.

Now, from the Blue Book entitled "Army Manufacturing Establishments," ordered by the House of Commons to be printed 8th April, 1878, it appears that the average cost of muzzle-loading Woolwich guns in 1876–7 was—

				£	
10-inch guns of	18	tons	each	74	per ton.
11 "	25	"	"	80	"
12½ "	38	"	"	90	"

Assuming the same rate of increase according to the weight, the cost of a 150-ton gun would be not less than £180 per ton; but even were it only £120 per ton it would cost £18,000, as against £4,500, the cost of the proposed system. It is impossible to guess what would be the cost of a 150-ton breech-loader at Woolwich, if such a gun could be made. Whilst in the Author's system the cost per ton would be very little more than that of the muzzle-loader.

The Author does not venture to estimate how long a time it would take to make a gun of 150 tons weight at Woolwich, nor what would be the cost of the needful machinery; but such a gun as he proposes could be built in three months from receiving the order to begin. He is aware that in practically working out a theory unforseeen difficulties may arise, and therefore he would not suggest the immediate commencement of a 150-ton gun, but rather that the system should be tried first, say in a 9-inch gun, and gradually extended.

The Author has no longer any other than a scientific interest in the question; but this would lead him to deprecate any experiment on this system not based upon the correct formula for the distribution of strains.

THE IRON AND STEEL INSTITUTE.

Abstract of the Address of the President, Mr. EDWARD WILLIAMS.

From "Engineering."

It is practically ten years since, in his inaugaral address, His Grace the Duke of Devonshire, to whom our Institute is under great and lasting obligation, laid before us not only the past history of the manufacture of iron and steel, but also its condition and amount at the time.

Since then few great industries have so increased and altered in character, and it is scarcely too much to say that an expert in 1869, who had abstained from following the course of things, would to-day find himself ignorant of at least one very important branch of the manufacture.

It will be understood that in treating of steel I am not at all referring to the old material that is so well produced at Sheffield by the crucible processes. With this our Institute has not so far dealt much; and I am afraid that our good friends of the crucible trade look upon us as unwelcome intruders, bringing cheap steel that sooner or later may in some degree clash with their specialty.

It is to steel in bulk for railway requirements and other constructive works, for ships, &c., that my remarks are intended to apply.

For the production of such steel the

world is indebted mainly to Mr. Bessemer, and in no small degree to our distinguished ex-president, Dr. Siemens, to both of whom Mr. Mushet's ingenious and most opportune invention is essential.

For both wrought-iron and steel the starting-point must be pig-iron, which so far has not been produced at moderate cost except by means of the blast furnace.

During the ten years I am speaking of there was not much alteration or improvement in this branch of the manufacture. The tall blast furnaces first introduced by Mr. John Vaughan, as well as our most efficient heating stoves, were in use at the commencement of the term, and though the number and size of them increased greatly, there was not, I think, much improvement in principle or advancement in efficiency.

It is perhaps not wrong to hold that our best blast furnace plant and appliances are unlikely to be much improved. A greater volume of blast and more security for regular charging and working would probably be in most cases beneficial; but in the important item of fuel consumption, it is doubtful whether any large economy will be found practicable.

The other raw materials are already utilized to the fullest extent, and in the item of labor there seems no great margin for economy.

The waste gases of the furnace, which at present heat the blast and raise the necessary steam, are, no doubt, capable of doing more duty as fuel; but in works consisting of blast furnaces only, it is not easy to see how this can be availed of. Where, in addition to blast furnaces, there are wrought iron and steel works close at hand—a combination likely to become prevalent—the more complete utilization of the gases will no doubt be taken advantage of.

In Cleveland, where there is a great deposit of salt, it is reasonable to expect that some day brine will be evaporated on a large scale by means of the waste heat, an enormous quantity of which is now being thrown away into the air from boilers, hot-blast stoves, and the several kinds of furnaces.

We many of us remember how we were startled when, in 1856, at the Cheltenham meeting of the British Association, Mr. Bessemer published his invention in detail. There was, among the prominent ironmasters of the time, pretty general doubt as to some of the principles he promulgated.

In less than a week from the reading of the paper, trial was made at Dowlais of the system of blowing air through pig iron, with complete success. What in outward form was pig iron, and only differed from it by having been blown through for a few minutes in the most haphazard way, was heated in a mill furnace of the common sort, and rolled into bars, to the great astonishment of all concerned. In fact, an experiment undertaken to show that Mr. Bessemer had fallen into mistake proved the exact contrary.

Shortly afterwards the system was set to work on a larger scale, but only very rarely was the success of the first experiment equaled, and generally there was so much irregularity and failure, that, notwithstanding the expenditure of a considerable sum of money, the operations were abandoned as unsuccessful.

When Mr. Bessemer left Dowlais, where he had been for some time, those who had worked with him believed that even he feared that the ingenious process he had advocated was not likely to prosper. But if so, his faith soon re turned; the clumsy converters first designed gave way to the beautiful tipping vessels; his works at Sheffield were started, and we owe it to his indomitable courage and perseverance that the world did not miss a great advantage.

In 1860 Mr. Ramsbottom was prevailed upon to try steel rails on the London and North-Western Railway, with a result so satisfactory that it needed no great sagacity to see that not even considerations of cost could long stand in the way of their extensive adoption.

In 1869, when His Grace addressed us, Mr. Bessemer had succeeded completely. Those who studied the matter perceived that for rails, at least, his process must entirely supersede the old iron-making.

It has long been beyond dispute that no skill and care can so weld together the many pieces of iron constituting a rail-pile as to make it equal, or anything like equal, to the solid ingot for rails to withstand the tremendous strain of heavy railway traffic. It is strange, however,

that, notwithstanding this, the inflation that, to our subsequent sorrow, came upon the iron trade after 1869 actually brought about a considerably increased make of built-up rails.

So late as 1875 our then President, Mr. Menelaus, who was, as he continues to be, in the forefront of the steel industry, gave in his address the chief place to puddling; and ironmasters generally looked anxiously for machinery to supersede hand labor. Now the case is very different. Puddling has been improved but little. The revolving furnace, upon which several years of skill and labor had been unsuccessfully expended in this country, was reported to have succeeded in America, and was from thence brought here in its most approved form.

It must, however, be admitted that, notwithstanding very full trial, our hopes have been disappointed, and only very moderate advantage has accrued from the several machines introduced to lighten the work of the puddler.

For rail-making the puddling forge has disappeared, and it is highly improbable that it will return. The place of it has been taken almost entirely by the Bessemer pit, which, in principle, general arrangement, and almost minute details, remains as it came from the hands of the inventor, and seems scarcely to admit of much improvement. Even the ingot mould, objectionable because of its inconvenient taper, has, so far, defeated all efforts to amend it, and continues in almost exclusive use.

Sir Joseph Whitworth, whose great skill and eminent services to engineering are notorious, has for a long time had in operation a system devised by himself of compressing fluid steel by enormous hydraulic power, and the advantage is said to be very great; but so far, I believe, the compressed steel has been but little used, except for armor to protect ships of war, and for the manufacture of guns.

In 1869 the make of Bessemer ingots in this kingdom was barely 200,000 tons; last year it was over 800,000 tons, the American make being nearly as much; and on the Continent of Europe it is very large and growing. The total make probably exceeded two millions of tons, with the prospect of enormous increase.

The open-hearth system, initiated, in this country at least, and so ably developed, by our late President, Dr. Siemens, whose regenerative furnace is of the utmost value, has also extended considerably. The make of ingots in 1878 was 178,000 tons in this country, with about as much abroad; in all, 350,000 tons.

For the very high classes of steel, where absolute soundness and great ductility are the first considerations, the open-hearth system is no doubt very efficient. The time necessary for the process allows of frequent testing, and there can be given to the metal exactly the composition desired.

The Siemens-Martin process is much availed of for converting old iron rails into steel, or, more correctly speaking, into ingot rails.

It would be well if we could agree upon a fuller and more accurate nomenclature of iron. At present we call steel everything made from cast ingots, though in composition and character, the metal varies from the hardest cast steel to the softest boiler plate, which has qualities almost like copper, and should therefore, I venture to think, be more accurately designated.

At the meeting of our Institute at Middlesbrough, nearly ten years since, this question was discussed, and the International Committee, appointed in America two or three years ago, suggested a new system of classification; but so far the recommendations have not, I believe, been acted upon.

It is inevitable that new rails made from old iron ones should be high in phosphorus, but to compensate for this they have liittle carbon and silicon, and in actual work they are said to stand well. On the table is a piece of the first Bessemer rail ever rolled. It was made at Dowlais, in 1858, from an ingot supplied by Mr. Bessemer, which, by the way, was parallel. A full analysis by Mr. Stead, of Middlesbrough, is attached to the sample, which has, as will be seen, 0.446 of phosphorus, a quantity that would frighten us in these days; but carbon and silicon are almost absent.

The ingots, of which that just mentioned was one, were rough and of most unpromising appearance generally, but they rolled perfectly. A second lot of ingots, received shortly afterwards, though similar in appearance, rolled very

badly, only three or four of them holding together, so as to make rails of any sort.

The reason of the difference, I am informed, was that the first came from a vessel lined with Stourbridge brick, and the second from the same vessel with an improved lining of gannister, which though much more enduring, no doubt had the effect of preventing any elimination of phosphorus.

It is unfortunate that no analysis of the second lot of steel exists. Twenty years ago we saw but dimly the importance of undertaking the chemical constitution of the materials we had to deal with.

For railway tyres steel has superseded iron almost as completely as for rails, and there is a movement in favor of steel ships which in all probability will extend; and when, as I suppose will be the case some day, the change is encouraged rather than retarded by the Board of Trade and other controlling bodies, iron plates will probably be to a great extent, if not altogether, supplanted.

For boilers, steel—Bessemer and Siemens-Martin—is in extensive use. Mr. Adamson, whose very able paper at the Paris meeting will not soon be forgotten, and who, I am glad to say, is about to add to it for our advantage, was one of the first, if not the first, to introduce steel boilers on a large scale, and we have it upon his high authority that the result is most satisfactory.

In the case of boilers no one can wish for anything but the greatest strictness to insure high quality, and therefore safety from accident; but it is difficult to see the advantage of insisting, as is the case at present, upon a like high and costly quality for the hulls of ships.

The iron supplied for this purpose is certainly not of boiler-plate quality, and I believe it is admittedly good enough.

Steel of fair quality is stronger than iron even after allowing for the reduced thickness permitted, and it is more reliable otherwise. There seems then no good reason why anything more should be demanded.

It is needless to say that every obstruction placed in the way of the manufacture and all superfluous cost incurrred are simply taxes upon the public.

Quite as unnecessary as the difficulties put in the way of steel for merchant ships is the objection to the taking of fluid cast iron direct from the blast furnace to the Bessemer converter. An opinion obtains in some quarters that the direct process is less under control, and the resulting steel may therefore be less uniform, than by the old mode of mixing several brands of iron and remelting in the cupola. Closer inquiry will show that this opinion is erroneous, and that remelting is less reliable than working direct.

In the laage way the only guide the practical man has is eye-judgment. Samples can be, and in all properly managed establishments are, frequently analyzed; but I need not say that it is impossible to examine chemically more than an infinitesimal proportion of the pig iron used, the bulk of which can have nothing in the way of examination beyond the careful inspection by sight of an experienced pig-sorter. In old times, when nothing more than this inspection was obtainable, it was a good additional safeguard to mix together half a dozen reputable brands of pig iron, that were very unlikely to be all wrong in the same chemical direction, and probably differed, when they differed at all, in ways that corrected each other; but the accurate knowledge of skilled furnace managers, advised by chemists whose everyday business it is to specify the proper mixtures for the blast furnace and keep out unsuitable materials, is far more certain. Given the proper ingredients, the blast furnace cannot make bad iron unless its mechanical working be disturbed by neglect or accident, which those accustomed to furnaces would find out quickly. Indeed, before the evil can have gone far the blast furnace itself and the converter may be depended upon to make prompt protest and compel the necessary attention.

My conviction is that, setting aside all question of cost, and considering only uniformity of quality, there is danger in remelting, and security without any disadvantage otherwise in the direct process.

It is not my intention to treat of the chemical and strictly scientific aspects of steel making, which are in the department of our well-proved guide, Dr. Percy, and his colleagues, and which our late President, Dr. Siemens, recently dealt with very ably. Nor will I venture to

consider the relative merits of iron and steel from the standpoint of the engineer. This is the proper province of the eminent men constituting the Institution of Civil Engineers in whose house we are.

Those who, like myself, profess only to be what, for want of a better name, we call practical ironmakers, are already greatly beholden to the theorists, to whom we must continue to go for accurate information, and whose directions we must carry out as best we can. In due time there will no doubt arise a race of composite men, who, having both theoretical and practical knowledge, will be abler and more efficient than we—the one-sided men of the present.

In the papers to be read at this meeting, and the discussions to follow, we shall, I doubt not, have much that is new and interesting in both departments of our great manufacture.

I cannot forbear to mention specially the important improvement patented and already brought to some practical success by Messrs. Thomas and Gilchrist for the dephosphorization of ordinary pig iron, thereby fitting it for use in the manufacture of steel.

The essence of the improvement is the substitution of a basic lining for the ordinary gannister lining of the Bessemer converter.

The idea is not now brought forward for the first time. On the contrary, the principle has long been known and availed of in the old process of puddling.

In 1872 Mr. Snelus patented the use of basic linings for furnaces and Bessemer converters, and I have no doubt it is in the recollection of many of you that more than one eminent metallurgist at home and abroad also recommended the change.

Those who tried it, however, one and all, encountered difficulties of a practical kind which stopped them. These difficulties, it is believed, have now been overcome.

With priority of invention and the rights of patentees our Institute does not interfere, and it is, I hope, needless for me to say that I do not desire to convey any opinion respecting them, our concern as an Institute being to investigate the merits of matters affecting iron and steel-making as a whole, and not at all to meddle with private rights.

Early last year at the works of the Blaenavon Iron Company, Monmouthshire, experiments were made by Messrs. Thomas and Gilchrist, with the aid of Mr. Martin, the linings being silicate of soda and limestone, which, however, proved unsuccessful because unenduring.

A larger trial at Dowlais shortly afterwards had the same result, though in all cases the phosphorus was eliminated, the difficulty being to maintain the lining, which was rammed into its place in the ordinary way. To meet this difficulty bricks of ground magnesian limestone burnt to great hardness were made at Blaenavon, and proved by actual experiment to be efficient; but unexpected circumstances connected with the company's affairs stopped the procedings.

Messrs. Bolckow, Vaughan and Company, of Middlesbrough, with their usual enterprise, undertook further experiments in a large way, and seem to have succeeded.

Knowing as you all do that only a small percentage of the pig iron in the world is suitable for making steel by means of either the Bessemer or the Siemens-Martin process, I will not weary you by enlarging upon the enormous advantage of an improvement that promises to make available almost all kinds of pig iron. In the paper about to be read by Messrs. Thomas and Gilchrist we shall no doubt have much information for which iron and steel makers generally are unusually anxious, and I venture to hope that Mr. Richards will favor us with the facts as a question of practical working.

At some recent experiments to which Messrs. Bolckow, Vaughan & Co., were good enough to invite the leading members of the local iron trade, the blowing was in every way successful, and the quality of steel produced excellent. The samples examined, several of which were made in our presence, varied in temper from the mildest and softest to the ordinary hardness for rails, any particular sort being produced at will. Samples to test were very easily taken, and it seemed that the exact temper of metal desired could be produced with certainty.

The converter lined with radial bricks of magnesian limestone is said to stand well, and the necessary addition of cold

basic material to the charge and during the blow, though of course it lowered the temperature at first, did not make a difficulty.

As yet there cannot have been any accurate ascertainment of waste, cost of lining, &c., but these are unlikely to be seriously against the new method.

One of the large vessels at Eston lined with basic bricks has been set to work, and it is believed that before long the cheap pig iron of Cleveland, without admixture other than that of spiegel, which is common to all, will be extensively used for making steel.

The North-Eastern Railway Company has already ordered a considerable quantity of rails made from Cleveland steel, which will be manufactured under the supervision of their eminent engineer, Mr. Harrison, whose report will be as eagerly looked for as it will be relied on implicitly.

If what is expected be in the main realized, great changes are likely. The manufacture of steel rails, which at present is much spread over the land, will, in all probability, grow in the localities where the necessary raw materials—iron ore mainly—are abundant and cheap, with the sea not far away.

Our former President, Mr. Bell, whose name will always be associated with blast furnaces, the theory and practice of which he has so thoroughly mastered and so lucidly explained, in communications not only to our Institute, but also to other scientific bodies, has for a long time been working to adapt Cleveland iron for steel-making, with, it is believed, considerable success, and I have no doubt it will be very agreeable to you if he can, during the coming discussions, describe his system and the results he has achieved.

By the changes of the last few years the relative circumstances of the several iron and steel producing districts of this country and of Great Britain in relation to other countries have been materially altered.

Before Mr. Bessemer's invention almost everything depended upon the cheapness of fuel and labor, the differing costs of ironstone, though important, being less vital. To make one ton of finished iron, taking rails and other kinds together, required on the average about six tons of coal, and the manual labor of many skilled men.

For steel much of this is unnecessary; the consumption of coal per ton of finished steel is already less than three tons, and likely to diminish.

When it is borne in mind that under the old system about one-third of all the coal raised in the realm was used at iron and steel works, and that the present total get is close upon 140,000,000 tons per annum, it will be seen how large a national gain this economy of fuel is.

In the item of labor the improvement is still more striking; more than half the money cost of it is saved already, while the very hard work is in a great measure dispensed with, as is also the need of long special training, without which, the old iron-making processes could not be carried on. If cheap and good steel had to recommend it nothing more than the already great diminution, and, as I believe, the coming abolition of puddling, it would deserve our gratitude. Those of us who have spent our lives in iron works know how hard and incessant the work of a puddler is, even with the best mechanical aids. We know also that, as the facilities for obtaining other employment became more numerous, the best men, who were not so wedded to the work that they could not leave it, drifted away into less arduous occupations, taking their sons with them, and how, in consequence, a metallurgical operation, upon the proper performances of which absolutely depends the quality of the resulting finished iron, got more and more into the hands of an inferior and less manageable class of workmen, with the result that could not fail to follow such a change.

The discovery of puddling is one of the bright events of modern times. But for it there would not have been a very large output of wrought iron, without which we should not have had many of the improvements of late years that have tended so greatly to the advance of civilization. But great as our obligation to puddling is, we part with it without regret, seeing that easier and more efficient means of achieving not only the same result, but a much better, have been devised.

In the time of transition from the old to the new and better system there must

be inconvenience and hurt to individual districts and special classes of men, but the national advantage cannot fail to be very considerable.

I need not say that there is yet a large amount of hand puddling which probably will continue for a long time. It will, I believe, steadily abate in amount, and I cannot doubt, though I say it with reluctance, knowing that the opinion is a little unpalatable to some excellent members of our Institute, that the day is at hand when, either by the Bessemer converter, or by the open-hearth, or by some other steel-making aparatus, there will be produced, with absolute certainty, with comparatively light labor, and I hope with fair profit to all concerned, every kind, variation, and quality of the metal iron which we now rudely designate steel and wrought iron.

It is interesting to remember how the old puddling furnace at its establishment resembled the Bessemer converter, and how it was improved in a way closely analogous to the change now in course of being worked out by Messrs. Bolckow, Vaughan, and Co., upont he system of Messrs. Thomas and Gilchrist.

As is well known, Cort's furnace had a sand bottom, and the quality of the iron from it was never certain—inferior always to the iron of the old process, viz., that of working in a bath of fluid oxide, which, though very wasteful, produced iron of excellent quality, and therefore lived on in great part despite the new invention and its economies.

For the Cort process excellent pig iron was made in cold blast furnaces from the best ores of the kingdom. The pig was refined in the old-fashioned refinery fires at great cost, and afterwards puddled on the sand bottom. The resulting wrought iron rolled badly, owing probably to the non-elimination of phosphorus, and could only be made into merchant bars of fair quality by repeated working in the mills, that involved heavy cost.

A man of great ability, long since passed away—Samuel Baldwyn Rogers—proposed a cast iron bottom for the puddling furnace instead of sand; and the suggestion brought not only the usual unbelief, but ridicule as well. That cast iron could be melted upon a cast iron bottom, and the bottom itself remain sound, was held to be unreasonable; and the suggestion of Mr. Rogers was treated as one of the erratic notions of a man who, though known to have ability, was certainly very eccentric.

After a time the first puddling furnace with an iron bottom was erected at Merthyr Tydvil, more than half a century ago, and so succeeded that it was adopted promptly. It was soon ascertained that puddled bars, instead of being, as formerly, unworkable stuff that would hardly hold together, rolled quite easily, and that a great deal of the costly mill-working might be dispensed with.

Gradually cheaper iron ores came into use, and there was less refining. Before many years in most districts of the country refineries were dispensed with, and pig iron puddled direct. The enormous heaps of discarded refinery and forged cinders, very good for many purposes as well as rich in iron, were worked up; and generally out of the invention of old Rogers came the greatest advantage to the manufacture of iron between the day of Cort and Bessemer.

For all this Rogers got little or no reward, except local celebrity of small worth, and a nickname; and, twenty years or so ago, he was by the timely intervention of a few friends rescued from the indignity of a parish funeral. Puddling in the Rogers furnace is puddling upon oxide of iron, and the change now being brought about in the Bessemer converter is in principle the same, namely, the substitution of a basic lining for a silicious one. Much the same took place in the case of the revolving puddling furnace. For several years the great practical difficulty was the lining. After trying almost everything likely to suit, it was found that sand only would endure for even a moderate time the action and wear of the operation, and from the sand-lined vessel the puddled iron was wretchedly bad. Mr. Danks hit upon a mode of lining with iron ore, which he preserved from destruction by charging oxide of iron with the heat; subsequently there was a further improvement in the same direction by the use of fluid tap-fettling run into a water-cased vessel, upon which it formed a lining. In both cases the improvement to the puddled iron was very great, owing to the removal of phosphorus; and but for the question of cost, and perhaps more than even that

the advent of ingot iron, the revolving puddling vessel would have done good service.

It is not to the credit of practical iron-makers that they so long failed to see, and indeed did not see until an amateur pressed it upon them, that the non-elimination of phosphorus by the Bessemer and Siemens-Martin processes was for the same reason that Cort's furnace and the early revolving furnaces did not remove it, namely, the sand linings and bottoms.

It is often said—sometimes upon seemingly good authority—that in the manufacture of iron and steel this country is losing ground, and that there is danger of our being excelled by our energetic brethren across the Atlantic, as well as by our more scientifically educated neighbors on the continent of Europe.

Without the least desire to help any particular view of the case, I have, by visiting Continental works, and by study of the available descriptions of the American works, which I hope to see some day, endeavored to ascertain how far this opinion is well founded. While I do not doubt that to maintain our leading position, and to acquit ourselves properly in the exact manufacture that has happily taken the place of the old finger-and-thumb business, we must by every means in our power add to and make general our knowledge of the composition and character of the materials we deal with, I do not think there is much ground for alarm.

That England, which has so far originated and worked out almost all the great improvements in the manufacture, should hope to monopolize, or anything like monopolize, the iron and steel trade of the world, is an unreasonable expectation, as I think it is also that in our own country, or indeed in other countries where there is commercial freedom, we are likely to be outstripped.

Steel-making has, as I have pointed out, rendered unnecessary much of the very hard labor for which our iron-making population is so well fitted, and has brought into requisition nicety of manipulation, and an amount of general education that unfortunately is uncommon amongst us, as I am inclined to think it also is with the great mass of the people of other countries.

But our better classes of iron-workers have great practical skill, and, unless my experience is exceptional, great aptitude to comprehend and adapt themselves to new processes.

In illustration of this is the fact that at present chemical terms and the appreciation of minute percentages, which even ten years ago were almost unknown, have become common and familiar; and I see no reason to fear that our rank and file of the future will be inferior to their competitors abroad.

In the matter of machinery for making and shaping iron and steel, as well as the mechanical aids that become more and more essential, we have not yet been outstripped, and are not likely to be.

After our late experience in France, where we were so openly and generously dealt with, we well know, if we did not know before, that there are splendid works abroad and, under the protection of import duties that keep away our competition, there are being established extensive and well arranged concerns for the manufacture of steel; but while we must greatly admire the works of Creusot, Essen, Terrenoire, Hayange, and many others, I do not consider that in the department of steel-making I understand, namely, that to meet the wholesome purposes of peaceful life, we are in even a second place.

Our members of the chemical sort are, no doubt, giving consideration to the progress of their special department at works abroad, Terrenoire especially, the direction and importance of which were so excellently shown in the Paris Exhibition last year.

In the manufacture of ingots there is much loss and needless cost by reason of the rough system of teeming. The only guide the workman has is a chalk mark which can scarcely be worked to, and the ever-varying internal capacity of the moulds makes anything like accuracy impossible. The effect of this is that ingots are always cast too heavy, and crop ends are made instead of finished steel. There cannot be any insuperable difficulty in the way of showing by an indicator the exact quantity of steel teemed, and so enabling a skilled workman to run ingots of any desired weight. If this can be done, not only will there be considerable economy, but some of the unemployed

iron-making mills will be available to roll steel in the old pull-over fashion, which has some advantages peculiarly its own.

For heating, the regenerative gas furnace is a great improvement; but it is believed, and I think Mr. Bell holds the opinion, that the waste gases from the blast furnace are capable of developing more heat by their proper combustion than is necessary for all the steam getting and heating after fluid pig iron, and that except the coke put in at the tunnel head of the blast furnace there should be no expenditure of fuel.

It is, I suppose, the fact that the ingot as it comes from the pit has more heat than is necessary for the rolling processes, the chilled outside being a shell holding a yoke of more or less liquid steel. Putting such ingots into an ordinary balling furnace is not therefore to heat them more, but to equalize the heat of the several parts. It would seem that for such equalization in a proper chamber only a very small expenditure of fuel, if any, is necessary; and if I am right, we may in this part of the manufacture expect a further important economy of coal.

There is, I think, great need of improved rolling machinery. We adhere too much to old types and systems, that were suitable enough for short lengths and light weights of a soft material, but which do not efficiently deal with hard ingots that are heavy and unhandy.

Mere strengthening of engines and roll trains of the antique sort will not, I am convinced, do, even with the addition of the reversing engine, which is beyond question a great advantage for rolling long bars, though less suitable for short things like blooms and plates. Either by roll before roll or by some entirely new system of shaping the steel there will probably be before long a change for the better.

In the scientific training of our overlookers and higher agents and managers there is room for improvement, and it seems to me much to be desired that educated intellectual young men, who now hang listlessly about the professions and so-called genteel occupations, which promise to them at best only respectable poverty, with the more than doubtful advantage of leisure, should break through the absurd old prejudice against seemingly rough work, and come over to the healthy business of iron and steel making, in which they may render the world good service, and obtain substantial remuneration by active employment of a very agreeable sort.

Of the higher management of great works I scarcely dare to speak; but as a rule, it really is not as it should be, and I hope to be forgiven for saying that there is need of amendment.

For some unaccountable reason it seems to have become the opinion that gentlemen without special training, often engaged in other business of an entirely different sort, and coming only occasionally to the works as directors, can adequately and efficiently control and manage great manufactories.

I am convinced that this is entirely fallacious, and that already there has been much hurt and loss by the system which in great part has obtained since manufacturing establishments became of unwieldy size, and passed from the hands of those who had grown up with them and understood every detail, into those of corporations and companies, unskilled in the necessary technical matters, without knowledge of the local circumstances, and wanting also the good personal relations that existed between their predecessors and the persons they employed.

It is not easy to name a business much more complicated and fuller of detail than the real management of a great iron and steel works, which, to be efficient, should have the constant attention of a competent staff, led and actually controlled by a technically-trained manager, skilled in the special business, and possessing, if possible, the somewhat rare quality which Motley, the American historian, well describes as "a gift which no training and no culture can bestow, and which comes from above alone by birthright divine—that which men willingly call master—authority." It would be invidious, though not difficult, to show where this kind of management has been the rule there is usually prosperity, and how many good and promising establishments have languished and are languishing for want of it.

There is, I think, a great future for iron and steel, not only in the few branches of the manufacture I have

referred to, but in each and all of them, notably, I believe, in the employment of blown metal for castings, that with no great additional cost cannot fail to be greatly superior in strength to any made from untreated pig iron, however good; and it will be strange if, in the state of general education that is coming, men like Cort and Rogers, Neilson and Vaughan, Bessemer and Siemens, Bell and Menelaus, and other able men at home and abroad, who have made the art of iron and steel-making what it is, do not arise in greater number to lead, improve, and strengthen it. That the workmen of our free country will be unequal to their duty, or fail in it, I do not believe; on the contrary, I hope and expect that, with better education and the great improvements it must bring, they will hold in the future, as they have held in the past, the foremost place for skill, endurance, and honest industry.

AN APPROXIMATE METHOD OF DRAWING EXPANSION CURVES.

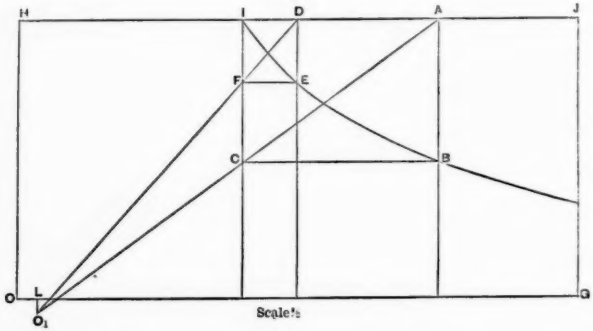
By CHAS. S. WILCOX.

Written for Van Nostrand's Magazine.

The following table A has been prepared for the purpose of giving an easy, and very nearly exact method of drawing several curves of the general form $pv^n = p_1 v_1^n$. In making out this table five values of n in most common use for the expansion curves of air and steam were employed, but from the formulæ given below a similar table can be made out for any other values of n. r is the ratio of expansion for which seven values have been taken for each value of n. x and y are the co-ordinates of a point the use of which will be explained.

The co-ordinates are to be laid off from the center O, Fig. 1, which in an indicator diagram is at the intersection of the vacuum and clearance lines v_1 and p_1, are

Fig. 1.



respectively the absolute volume and pressure of the air or steam at the point of cut-off. As an example, let it be required to draw the expansion curve $p\,v^{1.135} = p_1\,v_1$, when the vertical cut-off is at 0.4 of the length of the stroke as in Fig. 1. The unit of length has been taken one-sixtieth of an inch, of which OG contains 400 and OH 200. The value of x corresponding to $n=1.135$ and $r=0.4$ is from the table $0.086v$, or in this case, $0.086\times160=13.76$. The value of y for the same case is—$0.0416p$, or $0.0416\times200=-8.32$. These values of x and y are to be laid off in sixtieths of an inch, x from O to L and y from L to O_1. From this last point draw any line, O_1A intersecting the cut-off and steam lines,

A.

n.		1.0625		1.135		1.25		1.333		1.408	
r.		x	y	x	y	x	y	x	y	x	y
0.7		$0.0355v_1$	$-0.0278p_1$	$0.0720v_1$	$-0.0542p_1$	$0.1278v_1$	$-0.0926p_1$	$0.1603v_1$	$-0.0211p_1$	$0.1836v_1$	$-0.1482p_1$
0.5		$0.0389v_1$	$-0.0226p_1$	$0.0816v_1$	$-0.0460p_1$	$0.1423v_1$	$-0.0786p_1$	$0.1823v_1$	$-0.0991p_1$	$0.2161v_1$	$-0.1151p_1$
0.4		$0.0404v_1$	$-0.0209p_1$	$0.0860v_1$	$-0.0416p_1$	$0.1543v_1$	$-0.0690p_1$	$0.1979v_1$	$-0.0859p_1$	$0.2336v_1$	$-0.0994p_1$
0.3		$0.0481v_1$	$-0.0171p_1$	$0.0971v_1$	$-0.0348p_1$	$0.1765v_1$	$-0.0560p_1$	$0.2206v_1$	$-0.0702p_1$	$0.2660v_1$	$-0.0802p_1$
0.2		$0.0557v_1$	$-0.0134p_1$	$0.1130v_1$	$-0.0266p_1$	$0.2005v_1$	$-0.0424p_1$	$0.2574v_1$	$-0.0511p_1$	$0.3065v_1$	$-0.0572p_1$
0.1		$0.0740v_1$	$-0.0081p_1$	$0.1488v_1$	$-0.0156p_1$	$0.2625v_1$	$-0.0235p_1$	$0.3329v_1$	$-0.0272p_1$	$0.3897v_1$	$-0.0294p_1$
0.05		$0.0971v_1$	$-0.0046p_1$	$0.2009v_1$	$-0.0083p_1$	$0.3908v_1$	$-0.0119p_1$	$0.4206v_1$	$-0.0132p_1$	$0.4808v_1$	$-0.0137p_1$

and from the points A and C thus found, erect the perpendiculars AB and CB. Their intersection at B is a point of the curve, and in the same way any number of points may be found and the curve drawn through them.

The use of the Mariotte curve, or equilateral hyperbola, is so common in connection with expansion curves, that an exact method of drawing it by a similar construction may not be out of place here, although it is already known to some engineers.

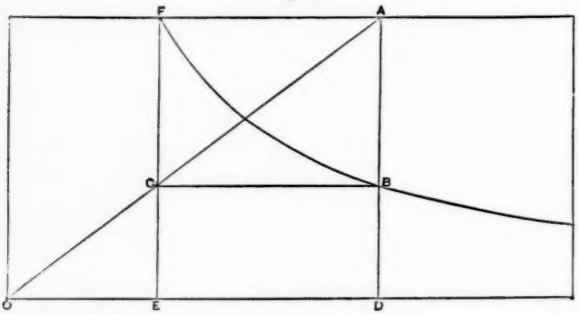
The equation of this curve is $pv=p_1v_1$ where p_1 and v_1 are respectively the absolute pressure and volume of the gas at some point where they are known, and p and v those at any other point. From the center O, whatever degree of expansion may be employed, draw the line OA as before, and from the points A and C, where it cuts the steam and cut-off lines, let fall the perpendiculars AB and CB. Their intersection at B will give a point of the curve exactly. For from the similar triangles OAD and OCE we have CF : OE : : AD : OD and consequently BD : OE : : FE : OD.

But OE and FE represent respectively the volume and pressure at the point of cut-off, F; and OD and BD those at the

B.

n		1.0625		1.135		1.25		1.333		1.408	
r		x	y	x	y	x	y	x	y	x	y
¼ to ⅝		$0.041v_1$	$-0.021p_1$	$0.084v_1$	$-0.044p_1$	$0.150v_1$	$-0.073p_1$	$0.190v_1$	$0.004p_1$	$0.225v_1$	$0.112p_1$
⅛ to ¼		$0.061v_1$	$-0.012p_1$	$0.12\ v_1$	$-0.023p_1$	$0.22\ v_1$	$-0.037p_1$	$0.277v_1$	$-0.045p_1$	$0.325v_1$	$-0.05\ p_1$
1/16 to ⅛		$0.083v_1$	$-0.007p_1$	$0.17\ v_1$	$-0.125p_1$	$0.318v_1$	$-0.02\ p_1$	$0.365v_1$	$-0.023p_1$	$0.444v_1$	$-0.025p_1$

Fig. 2.



point B, hence $p : v_1 :: p_1 : v$ or $pv = p_1 v_1$. Therefore the point B was correctly found. Other points may be found in the same way.

When great accuracy is not required, the values of x and y corresponding to several values of r in table A may be averaged as in table B.

The numbers in table A were obtained in the following manner: From the equation of the curve we know the co-ordinates of the points D and F and A and C, and by means of analytical geometry we can draw a line through them. The intersection of the lines will give the point O. The equations of these lines are:

$$\mu - \mu_A = \frac{\mu_A - \mu_C}{x_A - x_C}(x - x_C)$$

and $$\mu = \mu_D = \frac{\mu_D - \mu_F}{x_D - x_F}(x - x_D).$$

By combination and reduction, we have

$$\left(\frac{\mu_A - \mu_C}{x_A - x_C} - \frac{\mu_D - \mu_F}{x_D - x_F}\right)x = \frac{\mu_A - \mu_C}{x_A - x_C}x_A - \frac{\mu_D - \mu_F}{x_D - x_F}x_D$$

In this equation let us assume that $DH = HI + \frac{1}{4}IJ = v_1 + \frac{1}{4}(l - v_1) = v_1\left(\frac{3r+1}{4r}\right)$ and that $AH = HI + \frac{3}{4}IJ = v_1 + \frac{3}{4}(l - v_1) = v_1\left(\frac{r+3}{4r}\right)$. Putting for $\left(\frac{3r+1}{4r}\right)$, c and for $\left(\frac{r+3}{4r}\right)$, d and denoting the co-ordinates of D by v' and p' and those of A by v and p, we see that $x_A = v$, $\mu_A = p$, $x_C = v_1$, $\mu_C = \frac{p_1}{d^n}$, $x_D = cv_1$ $y_D = p_1$, $x_F = v_1$, $\mu_F = \frac{p_1}{c^n}$ Substituting these values in the above equation and reducing we have

$$x = \frac{dp_1\left(\frac{d^n - 1}{d_n}\right)(c-1)v_1^2 - cp_1\left(\frac{c^n - 1}{c^n}\right)(d-1)v_1^2}{v_1^2(d-1)(c-1)}$$

$$\frac{p_1\left(\frac{d^n - 1}{d^n}\right)(c-1)v_1 - p_1\left(\frac{c^n - 1}{c^n}\right)(d-1)v_1}{(d-1)(c-1)v_1^2}$$

Substituting A for $\left(\frac{d^n - 1}{d^n}\right)(c-1)$ and B for $\left(\frac{c^n - 1}{c^n}\right)(d-1)$, we have, after reduction,

$$x = \frac{d - \frac{B}{A}c}{1 - \frac{B}{A}}v_1.$$

Again writing the equations of the two lines under the forms $\mu - \mu_C = \frac{\mu_A - \mu_C}{x_A - x_C}(x - x_C)$ and $\mu - \mu_F = \frac{\mu_D - \mu_F}{x_D - x_F}(x - x_F)$, we have, after combination and making the same substitutions as before, $y = \frac{\frac{B}{A}\frac{1}{d^n} - \frac{1}{c_n}}{\frac{B}{A} - 1}p$.

It will be seen from the substitutions made, that the points of the curve obtained from the use of the table will be exactly correct at two places; namely, those whose abscissas are $\frac{1}{4}(l - v_1) + v_1$ and $\frac{3}{4}(l - v) + v_1$. At other points the deviation from the true curve will be generally insignificant.

THE ARTISAN OF JAPAN AND HIS WORK.

From "The Builder."

In Japan, the skilled workman is socially the superior of the trader, and the carpenter is foremost and most important; in fact, he is called *Dai-ku* [great workman], and is architect, builder and joiner; although for the minor branches there are special terms used, and the subdivision of labor is carried out to a greater extent than in other trades.

When it is proposed to erect a building, or rather the series or group of buildings that constitute a residence or a place of business, the master carpenter is called in, a plan is discussed, and the outline fixed upon; in the course of a few days, perhaps, the estimates are prepared, at so much per *tsubo* (of 36 superficial feet), measuring from the center of the corner uprights; a plan is drawn to a large scale on a board, ground-plans, elevations, &c., the *ken* (of 6 feet) being the unit of measurement. The ground is then marked out, carefully measured and leveled with a water-level—this is a piece of 4-inch or 6-inch square stuff, which is planed level and square, with a groove in the upper side, with also a small hollow in the center, and one near each end. The water is poured into the center, and the "level" propped up until the hollows at both ends are quite full of water, and consequently level. Of course, when the surroundings do not arbitrarily debar a choice of frontage, a southern aspect would be preferred, the north-east being most objectionable. Certain rooms would be placed in "lucky" parts, and the astrologer and soothsayer must be consulted. The position of the kitchen, the altar for the household gods, and other details, having already been decided in accordance with well-known fixed rules of procedure, a lucky day must be chosen upon which to break ground and commence the foundation. Unless a large building or a fire-proof storehouse is to be erected, the foundation will give but little trouble; however, the "ground-worker" must be next called in; this is the class similar to our "navvy," and from which the "fire-brigade" is chosen. Should a very solid foundation be required, piles driven, &c., a scaffolding is erected, and a large rammer, made of hard wood, is used, varying in size according to the circumstances, with a heavy iron band on the lower end, and just above which a number of ropes are attached, one for each man. There are two slight poles attached, parallel to the axis of the rammer, used by one of the men above to guide, while the others, who are mounted on the scaffold, lift it by the ropes and let it drop; the foreman remains below to guide the head as it drops, with the aid of a short piece of rope. While working at this the men chant a chorus of the most peculiarly hideous and noisy character, an old custom, which, they say, drives away the evil demons; certainly it is frightful enough in its way; it affords opportunities for jests and by no means choice language, for these "workers of the soil" are a very rough lot. The foundation is usually formed by scraping out a few inches of earth and ramming down some rubble, upon which is laid a course of rough-hewn stone, the ordinary size being about 10 inches to 11 inches square, and in 2 feet to 3 feet lengths, basalt, granite, or sandstone, as may be necessary or advisable; the latter is the cheapest, of course. Upon this is usually, in the better class of construction, a course of clean-dressed stone of better quality, upon which will rest the frame of the building, uprights to support the floor, or in the case of large heavy roofs, center posts are rested upon large blocks of stone with a step cut in them to prevent slipping when the house is shaken by an earthquake.

There is little opportunity for the stonemason, or the quarryman that supplies him with materials, to exhibit his skill here, but of these more hereafter. They have no idea, however, of the "natural bed" of stone, facing it on the side most easily worked.

While this has been doing, the "contractor" has been to the timber merchant to arrange for delivery of timber as required. The bulk of the stock is stored in shallow ponds, stacked up so as to keep it completely submerged, and the

Japanese tradesman prefers the wet timber to work upon. Timber is rough-hewn into lengths that will give clean timber of 6, 9, 12, 15 and 18 ft. lengths, and for square stuff a mortise also; the large timber is then taken to the "works," and there cut up into the sizes required.* These "sawyers" form a special branch of trade.

To prevent the timber splitting and warping, the Japanese take a half-cut to the center and parallel to the heart, and fill it up with a slip, as the wood dries and the cut "gapes" or expands.

The carpenters take their measures from the "working plan" already mentioned, and the roof, composed of rough crooked timbers, is placed together by most builders as they are cut, although there are some who scorn to do so, depending entirely on the accuracy of their plan and measurements; every joint and every piece is marked ready to put together. When the frame is completed, a lucky day is selected to erect it, and this is very speedily done, for the carpenters and friends are eager to set to work at devouring the good things provided upon all such occasions.

The details of the processions, the various superstitions, etc., interesting though they undoubtedly are, cannot be introduced here, as they would occupy too much space.

Most of the partitions and walls of a Japanese house are formed of sliding panels, either covered with semi-transparent paper, or else thickly and strongly papered on both sides for inner partitions; some portions of the inner partitions and outer walls being of plaster, a framework of small-sized and split bamboo is used, upon which mud and stiff clay are plastered, coat upon coat, at least three coatings, and then finished as necessary.

The plasterer is the "right hand" of the carpenter, and ranks next him; he is usually more of an artist, the better tradesmen being highly skilled in ornamental and fancy plaster work. Lime made of burnt shells is much used, and it is mixed with size extracted from sea-weed by boiling; outer walls are generally protected by thin weather-boarding, which is colored with lamp-black and the same kind of size as that already mentioned. Broken shells, pure gravel, and coarse brilliant sand are often used for portions of interior walls plastered, and give a very pleasing appearance to the room, as a contract to the neat matting and daintily-papered screens and panels. The roofs of dwelling houses of the better class are tiled; they are first boarded with $\frac{3}{8}$ in. pine, then thin split shingles; sometimes the bark of the *cryptomeria* or *retinispora* is laid on this, but invariably a large quantity of clay or river-mud is used to "bed" the tiles in.

Fireproofs are so successful in resisting the fierce heat, if of short duration, that they withstand the sweeping conflagrations that occur in the Japanese cities. A wooden frame with a lacework of bamboo forms the foundation for a solid mud structure that becomes as solid as a fire-brick, and stands firm long after the wooden frame has decayed.

The Japanese will remove a house, even one of their large heavy fireproofs, for a long distance. Securing crosspieces to the main uprights, they raise it off the foundations with a number of long balks for levers, to the ends of which heavy stones are attached. The foundations removed, timber is substituted, and small rollers (about 2 in. diameter) are used, planks of hard wood being laid down, between which the rollers work.

Brick and tile makers will be mentioned fully hereafter. We must now return to the finished house, and see about fittings and furniture.

The mat-makers keep a stock of mats ready to be covered. These are made of rice straw which has been beaten flat and woven and sewn together until it is about 1 in. thick, 3 ft. wide; and 6 ft. long. This core is covered with fine matting, turned round the ends, and the sides are bound with a coarse linen border 1 in. wide, black, or white with spots for some special purposes. Considerable experience and judgment are required in fitting the mats and laying them down, so as to wear well. The traffic should be with the grain, and nothing appears so unsightly as a badly-matted room.

The sliding panels that form a partition are either in pairs of 3 feet each, or in fours, filling a space of either 9 feet or 12 feet. These are papered on both sides, with a wooden border. The

* The tools used are peculiar, and deserve description, but illustrations only can give any idea of them.

method of securing this border, without nails appearing, is curious, and, as the border is generally neatly lacquered, a matter of some consequence.

The windows are sliding pannels, outside of which rain-shutters are fitted, to be closed in stormy weather, and nightly.

The aforesaid panels are supplied by a branch of the carpenters, and are kept in stock ready made and well seasoned, of all qualities. The cheaper are made of *Cryptomeria*; indeed, this wood forms the principal building material. The better class of fittiugs, and some portions of the more expensive houses, are made of *Retinispora obtusa*. Fancy woods are used to a small extent only.

In the reception and living rooms there is invariably a recess, raised some 3 inches, with a border of lacquered or fancy wood, in which are hung pictures, and where flower-vases and swords are mostly seen; in fact, it seems this recess has been the especial place for the sword and art objects. Some rooms have little cupboards, sets of shelves, &c., fitted, so that there is plenty of opportunity for the *dai-ku* to display his good taste and ability as a designer.

The Japanese workmen and artists do not proceed at random; there is a systematic training based on ancient custom and precedent; hand-books, with elaborate instructions, and progressive lessons, are cheap and accessible to the poorest, for circulating libraries abound. From first strokes to the finished drawing, and for each class or style of design, there are many elaborately illustrated works that can be referred to.

The blacksmith does not contribute largely to the ordinary dwellings, but the metal-worker in small articles is an important person; there is a great amount of small ware needed in the way of hinges, hasps, plates to hide corners, and other joints, where the hand touches the panels in opening and closing, and in trifles about the house.

The worker in metal is without exception the most artistic of Japanese tradesmen, and the least dependent upon others' skill; he deserves special notice. Although the blacksmith and the nail-maker are kindred branches, yet the latter is but a secondary personage; iron nails are not extensively used; even cheap, foreign-made nails find but little sale.

The house being furnished and fitted, a general cleaning up precedes the grand ceremony of entering upon occupation thereof. The chests of drawers (made of the timber of the *Paulownia imperialis*), —of the several members of the family, each lady has at least one, her toilet and mirror stands, work-box, &c.,—are moved in, and placed in their appointed places behind sliding-panels in recesses specially constructed. Then come in the large bedding-chest and its contents, the kitchen furniture, and the small stands, bowls, &c., for each member of the family has a set of utensils, the greater portion of all of which are of wood, lacquered.

METHOD OF BLASTING ROCK FOR THE LYTTLETON HARBOR WORKS, CANTERBURY, NEW ZEALAND.

By GEORGE THORNTON, Assoc. Inst. C.E.

From Proceedings of the Institution of Civil Engineers.

The works at Lyttleton Harbor, Canterbury, New Zealand, consist mainly of two rubble breakwaters, enclosing an area of 115 acres; one extending from Officers Point for a length of 2,010 feet, and 40 feet wide at the top, the other from Naval Point for a length of 1,434 feet, with a top width of 25 feet. There are, besides, various wharves and jetties to accomodate the shipping and railway traffic; and a considerable amount of dredging has been carried out in the harbor.

The formation of the cliffs at Officers Point and at Naval Point, from which the material was obtained for the construction of the works, is volcanic, ranging from compact basalt to agglomerate

beds and layers of scoria and tufa, intersected by numerous trap dykes. The strata are thus very irregular and varied in their character.

The system pursued by the contractors for the breakwaters was well calculated to furnish an abundant supply of rubble suitable for the protection of the seaward face of the works. The whole of the excavation was done by means of mines, and the arrangements were so admirably planned and carried out, that at no stage throughout the three years and upwards during which the works were in progress, was there any deficiency of large rubble. No difficulty or danger was experienced; and large vessels were not removed on the occasion of a mine being fired, although moored but a few yards distant —the nearest mine being 93 yards, and the most distant mine being 233 yards from the shipping.

An electric battery was at first used to discharge the mine. This resulted in failure, and the loss of 6 tons of powder in the chambers unexploded. Afterwards a second attempt resulted in partial failure, although skilled electricians were employed in both cases. The contractors then decided to resort to the ordinary powder train, which was subsequently adopted with singular success. The train consisted of a piece of pine timber, 4 inches wide by 3 inches deep, with a V groove cut out of it, in which the powder was placed; over it a cover-board, 4 inches wide by 1 inch deep, was screwed down. To insure instantaneous combustion in all the chambers, a plan of each mine was prepared on the wharf, and the respective distances the fire would have to travel were accurately measured and laid down on it. As the chambers were at various distances from the mouth of the mine where the train was lighted, the fire was made to travel the same distance to the nearest chamber as it had to the farthest, by returning the train until it was exactly of the same length. It will be readily understood that the explosion of one chamber a few moments before the others would impair their efficiency, and therefore the greatest care and precision were necessary; and, in order that nothing might be left to chance, experiments were made with the train laid in position on the wharf exactly as it would be in the mine, by lighting it, to ascertain if instantaneous explosion resulted throughout. By a similarly careful study and experiments the proper quantity of powder necessary in each chamber was ascertained, according to the line of least resistance, height of cliff, &c., and generally the results were as anticipated. A fuse of about 12 feet in length was used, which burnt about five minutes. The largest mine exploded contained 15,900 lbs. of pebble powder in eight chambers, and dislodged upwards of 40,000 cubic yards of rock. The smallest mine fired contained a charge of 2,240 lbs. of powder. The total quantity of powder used for both breakwaters was 104½ tons, giving an average expenditure of 4.74 oz. of powder to each cubic yard of rock dislodged.

The heights of the quarries, which were left with vertical faces on the completion of the works, were, at Officers Point 125 feet, and at Naval Point 90 feet. Every possible care was exercised in charging the mines. It being found that if the powder was packed closer in the chambers that the barrels would admit of, greater effect was produced as affording less air space, the contents of the barrels were emptied into bags. These bags were placed in a box to collect any loose powder, the ground immediately round being watered. Boots without nails were supplied to the men entrusted with the charging of the mines, and lamps only were used.

PRESENTATION OF THE BESSEMER MEDAL.—At the meeting of the Iron and Steel Institute of Great Britain in London, on May 7, the president rose to present the Bessemer Medal of the Institute to Mr. Peter Cooper, the "father of the American iron trade." He said that Mr. Cooper had commenced life in the far away times before the King and Queen of France came to so tragic an end at the latter part of the eighteenth century, and he had been ever since engaged actively in the every-day business of life, having earned for himself during his long life the highest possible respect among all sorts and conditions of people in the United States. Mr. Cooper's special connection with the iron trade commenced more than fifty years ago, and had continued to the present time. In

1830 he built the largest rolling mill in his part of the country, at Baltimore. In the same year he built from his designs, and afterwards drove the first locomotive made in America. He erected afterwards, in 1845, the Trenton Works, then the most extensive rolling mills in the United States; and all of them knew how he established, twenty-five years ago, the great Cooper Institute, which is now giving excellent education, and the education was of a technical kind that we desired to extend among the iron makers. Considering all things, the Council came to the conclusion that Mr. Cooper, from the close connection with our brethren across the Atlantic, and that they are the second great iron and steel makers in the world, ourselves being the first—but likely to have something to do to maintain our position—the Council came to the conclusion that the fit and proper person to receive this medal was Mr. Peter Cooper, and, for his own part, he hoped the meeting would approve of the decision of the Council. Mr. Cooper had addressed a letter to Dr. Siemens, thanking him for the communication of the offer of the Bessemer medal, which the president read as follows:—

"New York, April 15, 1879.

"C. W. Siemens, Esq.,

"President of the Iron and Steel Institute.

"Dear Sir:—Your favor of the 4th instant, announcing that the Council of the Iron and Steel Institute has resolved to award to me the Bessemer medal for 1879, in recognition of my services in the promotion of metallurgical science, has given me great pleasure, and I do not feel that the services, which the Council thus rates so highly, have entitled me to such a distinction, although it is true that I have for many years taken a deep interest in the progress of the iron and steel manufacture, and I have always considered it a service as well as a duty to encourage useful improvements in that business, and new industrial applications of its products.

"In transmitting through you my acceptance of the unexpected honor which the Council of the Institute has conferred upon me, permit me to thank you personally for the very cordial and flattering terms in which you have conveyed its decisions.

"Regretting my inability to be present at your approaching annual meeting, I beg leave to name my friend, Mr. I. L. Bell, who, I trust, will kindly consent to represent me on that occasion. Should Mr. Bell unfortunately be prevented from attending, perhaps my friend, Mr. Geo. J. Snelus, will find it convenient to take his place. I remain, with high respect and esteem, yours very truly,

Peter Cooper."

Mr. I. L. Bell, M. P., said that after the remarks which had fallen from the president, and the letter which had just been read, it was not necessary to detain the meeting more than a minute in fulfilling the office which his venerable and highly respected friend, Mr. Cooper, had invited him to undertake. Their president had so well set forth the claims of Mr. Cooper to the distinction accorded him by the Iron and Steel Institute, that little remained for him to say. He might, however, say, with regard to the Cooper Institute, that at the time Mr. Cooper erected the building he had expended, and he knew that he was about to expend, every farthing of his realized capital up to that time. Such a service to scientific instruction they might look for almost in vain in the history of science. He was quite satisfied that Mr. Cooper highly appreciated the compliment which had been paid him, and it was only his great age—being over ninety—and the distance from New York to London, that prevented his being present to have accepted the distinction in person at their hands.

Mr. Snelus said that so great was Mr. Cooper's anxiety that the medal should be received by some one, that when Mr. Cooper heard that Mr. Bell had been ill recently, he sent a letter to him (Mr. Snelus) to acknowledge the compliment, and to tell them how grateful he was for the award they had offered him. He was sure that the Council of the Iron and Steel Institute could not have given it to a better representative of the United States than that venerable and distinguished gentleman.

REPORTS OF ENGINEERING SOCIETIES.

American Society of Civil Engineers.—The March, April and May Transactions have just come to hand. The first is devoted exclusively to Lighthouse Engineering, and is

abundantly illustrated. The paper was presented by Gen. J. G. Barnard.

The April No. is a paper by Lieut. Col. B. S. Alexander on the Minot's Ledge Lighthouse.

A single paper No. 180, "On the Construction and Maintenance of Roads," by Edward P. North, fills the pages of the transactions for May. The illustrations of Mr. North's paper represent the Rollers employed for asphalt pavements and cross sections of streets.

ENGINEERS' CLUB OF PHILADELPHIA.—*Meeting of May* 17, 1879.—Mr. Chas. G. Darrach spoke of the improvements made on what is known as No. 5 Turbine at Fairmount, built in 1871 by Mr. E. Geyelin. The gearing has been entirely disconnected from the walls of the house, allowing 15 revolutions per minute instead of 11 as heretofore.

Mr. Geyelin has now constructed new runners and guide wheels with cycloidal curves, and provided with a partition dividing the buckets vertically into an outside wheel having 1400 square inches of outlet, and an inside wheel having 700 square inches of outlet. These wheels replaced those made in 1871, having a total measurement of discharge of 2400 square inches. This inside area is cut off by an automatic inside gate, at low tide, and a consequent saving of water as the result, as 16 hours out of the 24 the inside division of 700 square inches remains entirely closed.

The wheel was designed to pump eight million gallons, but until these improvements it has pumped but 5½ million gallons per day as an average maximum. No difficulty whatever is experienced in pumping eight and one half million gallons per day, and Mr. Geyelin expects to be able to make the other wheels pump ten million per day with a smaller amount of water than they are now using to pump six million gallons.

Mr. J. H. Harden read a paper on "Schmitt's Revolving Screen." This Screen is used in the coal districts of Germany, and was brought to the attention of the writer by a paper by Mr. D. P. Morison, published in the April number of *The Transactions of the North of England Institute of Mining and Mechanical Engineers.* Mr. Harden's paper was illustrated by drawings, without which it is difficult to give a good idea of the Screen, which consists of an iron plate fifty four feet long by four feet wide rolled into a spiral, in the convolutions of which are the perforations for separating the different sizes. The advantages of this Screen over the old forms are:

1. Less cost and decreased space in proportion to work performed.

2. Coal is not so much broken, as the distance traversed by the large lumps is smaller; and the work done is more efficient.

3. Construction is simple and strong and the parts are readily accessible for repairs.

4. Less power required to drive, the matter being more evenly distributed, and not lying entirely in the bottom of the Screen.

Mr. Rudolph Hering exhibited models of connections to be used in joining house drains to sewers. These connections are terra cotta blocks, sixteen inches long by twelve inches wide, having a projecting pipe into which the drain from the house fits. The projection from the block is at an angle of 45 degrees with the axis of the sewer in order that there may be no checking of the flow when the drainage from the house enters. In the case of pipe sewers, a section of pipe is made with the connection. These blocks are built into the sewer at intervals corresponding with the width of the house lots on the street; and are are made of different shapes in order to fit any position, though the usual place is at the springing line of the arch.

Mr. Hering spoke at length on the change which has taken place in the last hundred years in the formula for determining the velocity of flow of water in pipes; and showed that as new conditions entered into the problem the accepted formula would be superseded by one which met those conditions, until "Kutter's formula" was evolved by combining the others, all of which had been correct for the conditions of the experiments on which they had been established.

In the discussion which followed Mr. Herings remarks, Mr. C. G. Darrach said that he had found in a series of fifty-two experiments, communicated by him to the Am. Society of Civil Engineers, that equal increments of velocity produce equal increments of pressure, or friction head; and that he had found Kutter's formula inapplicable in these experiments.

CHARLES A. YOUNG,
Corresponding Secretary, pro tem.

IRON AND STEEL NOTES.

CRYSTALS IN FOUNDRY PIG.—In investigating certain sulphur compounds contained in the graphite of meteoric iron Mr. Lawrence Smith was led to study the artificial product foundry pig (*font de fer*), and he has communicated the results to the French Academy of Sciences. This last, like meteoric irons, contains graphite, and it is admitted this substance owes its state of extreme division to the manner in which it is separated from its solution in the molten metal at the moment when it assumes the solid state. Mr. Smith has experimented on the pig itself previously reduced to fine powder. If this iron thus divided be agitated with ether or petroleum, or more simply if one of these solvents be let run through iron filings placed in a glass tube, there at once occurs the spontaneous evaporation of the liquid with the formation of acicular crystals, absolutely similar to those given by meteoric graphite The quantity of these crystals varies with the quality of the pig-iron used, but success may be expected with most kinds of iron if from twenty to fifty grammes of the powdered iron be operated upon. Heated in a tube the crystals in question quickly melt. At a higher temperature they volatilize, leaving a carbonaceous residue generally smaller than that from the meteoric crystals. The principal part of the substance consists of sulphur. Mr. Berthelot had obtained similar crystals by treating iron sulphides, artificial or natural (protosulphide, bisulphide, pyrrothine, &c.), with ether or alcohol. From this Mr. Berthelot at-

tributes the presence of the carbon to the solvent employed. Mr. Smith, however, did not exactly see how one could thus explain the various proportions of carbon associated with the sulphur according to the material experimented with, and which is relatively so large, especially with the Orgeuil meteorite Mr. Berthelot remarked that from an examination of Mr. Lawrence Smith's specimens they appeared to him to be identical with a material he had obtained by the action of perfectly pure ether as well upon octohedral sulphur as upon the anhydrous sulphides of iron. In every case the compound contained, as well as carbon and hydrogen, a considerable quantity of combined sulphur, independently of the pure sulphur, which first separates in crystals during the evaporation. The formation of the same substance with pig-iron, discovered by Mr. Smith, is probably due to the presence of a trace of sulphide of iron in the pig itself. It will thus be seen the solvents, regarded as neutral, are far from acting in every case as a mere solvent of the bodies put in contact with them without ever altering them chemically. Mr. Berthelot concludes: These results are of a nature to call for great reserve in all conclusions relative to the pre-existence in meteorites of these crystallizable hydrocarbonaceous matters, which are susceptible of being extracted from them by organic solvents such as ether or alcohol.

RAILWAY NOTES.

It is stated that the Midland Railway Company are arranging to provide their goods and mineral wagons with continuous brake power. Hitherto, although something has been done in this way for passengers, nothing has been attempted for the safety of the railway servants engaged in running the enormous traffic in goods.

A French engineer, named Duponchel, has made a report on the projected railway across the Desert of Sahara, from Algiers to Timbuctoo, a distance of 2500 kilos. We called attention to this more than a year ago, but it does not seem that the principal difficulty, the want of water, which is not to be procured in that region, has been overcome. M. Duponchel calculates that for three trains daily the amount of water required would be 4000 cubic meters, and that the engineering science of the day is quite sufficient to supply even a much greater quantity at the requisite points. But what as to cost?

The survey for the Russian railway in the Caucasus, between Vladikavkaz and Tiflis has been completed, and the plans are stated to have received the assent of General Possiet. The line will be 183 versts long, with a good many tunnels, and will cost 22,000,000 roubles, or about 120,000 roubles a verst, £15,000 a mile. The Caucasian range will be crossed at Kobi by a tunnel six versts long, 512 feet below the existing post road. It is not expected that the Tiflis-Erivan line will be commenced until the Vladikavkaz railway has been completed, but the line from Baku to Tiflis, connecting the Caspian with the Black Sea, is being very energetically pushed forward.

The Board of Trade report on the railway accidents and casualties during the year ending 31st December, 1878, has appeared, and is thus, we are glad to say, earlier than usual. From it we learn that accidents to trains, rolling stock and permanent way, during the year, caused the death of 39 persons, and injury to 1329—viz.:—Passengers killed, 24; injured, 1173; servants of companies killed, 15; injured, 156; total—killed, 39; injured, 1329. During the twelve months there were reported 53 collisions between passenger trains or parts of passenger trains, by which 13 passengers were killed, and 452 passengers and 14 servants injured; 98 collisions between passenger trains and goods or mineral trains, engines, &c., by which six passengers and one servant were killed, and 537 passengers and 38 servants were injured; 28 collisions between goods trains or parts of goods trains, by which five servants were killed and 30 were injured; 76 cases of passenger trains or parts of passenger trains leaving the rails, by which five passengers and two servants were killed, and 106 passengers and seven servants were injured; 15 cases of goods trains or parts of goods trains leaving the rails, by which 7 servants were killed and 28 were injured; 16 cases of trains or engines traveling in the wrong direction through points, by which 13 passengers and nine servants were injured; 20 cases of trains running into stations or sidings at too high a speed, by which 41 passengers and three servants were injured; 169 cases of trains running over cattle or other obstructions on the line, by which three passengers and four servants were injured; 10 cases of the bursting of boilers or tubes, &c., of engines, by which 14 servants were injured; five cases of the failure of machinery, &c., of engines, by which one servant was injured; the failure of 1034 tires, one of which caused injury to one servant; the failure of 540 axles, causing injury to four passengers and four servants; 16 cases of the failure of couplings, causing injury to seven passengers and two servants; the fracture of 490 rails, causing injury to eight passengers; and eight accidents of a miscellaneous description, causing injury to two passengers and one servant — *Engineer.*

ENGINEERING STRUCTURES.

Excavations and Foundations in Sand.—M. Plocq has published an interesting note upon the recent harbor improvements at Dunkerque and Gravelines. There are ten sluices for controlling the fresh and salt waters of the districts, for various purposes of maritime and domestic economy, as well as for the wants of the military service and for defensive operations in time of war. The sluices are built in a soil which is wholly made up of pure sand, of flour-like fineness, reaching to a depth of 15 or 20 mèters (16.4 to 21.9 yards) below the lowest tidal levels. The works were all executed by the help of cofferdams, in preference to dredging, and the preparations were so

thorough that it was always easy to work in dry sand even at the lowest foundation levels. The total cost was less than half what it would have been by the whole method of dredging, and the saving of time was in about the same ratio.—*Ann. des Ponts et Chaussées.*

ST. GOTHARD TUNNEL.—A serious difficulty has occurred between the St. Gothard Tunnel Railway Company and the contractor, M. Favre. The company wished to mortgage all the works of the line and those of the tunnel. M. Favre objected to this because it imperilled his interests. The company then changed the system of operations. The contractor, being bound to complete the work at a fixed date, had prepared the materials for the entire lining of the tunnel. The company determined to line the tunnel only at intervals of from 4 to 70 mètres, with gaps of equal extent. The materials already prepared become, therefore, partially useless; the security of the navvies and of the tunnel is seriously endangered, for the nature of the soil renders a continuous lining as necessary as ever, and the contractor can no longer make use of his boring machines, for the diameter of the tunnel will vary according to whether it is to be lined or not. The company deliberately, it is alleged, placed obstacles in the contractor's way, with a systematic attempt to make him throw up the work, so as to enable the company to take possession of the tunnel and include it in the mortgage promised to the bankers, from whom they obtained an advance of about £3,000,000. By order of M. Favre, 1,200 of the workmen lately employed in the Gothard tunnel were discharged. Great excitement prevails on this subject at Berne.

ORDNANCE AND NAVAL.

HERR KRUPP'S ORDNANCE EXPERIMENTS.—The Berlin correspondent of the *Standard* states that "the programme of the ordnance trials, to take place at Herr Krupp's manufactory in July, includes no fewer than twenty-five different experiments, extending over four days. The experiments will, it is anticipated, far exceed in interest those of 1877 and 1878, many of the forthcoming performances being entirely new. Besides the experiments with the new 40 centimeter gun, whose capabilities of opening and closing, velocity, and degree of gas pressure will be tested with twenty charges, the capabilities of a 2.5 centimeter revolver-cannon are to be tried, for the first time, with ten charges at 1000 paces. Then follows a trial of Krupp's iron-plated guns, for which a 15.5 centimeter gun will be employed. The resistance of the plating will first be investigated, then the firing capabilities of the gun tested with thirty charges, and finally the result will be verified with another piece of the same description of ordnance in an additional two rounds. The 21 and 28 centimeter howitzers, a 15 centimeter rifled mortar, and 9.6 centimeter field-piece will be likewise employed for various experiments. The greatest distance at which trials are to be made will be in the case of the 10.5 centimeter siege-piece, which is to be fired at 10,000 meters, and the 15 centimeter gun, which is to be tested at 4,000 meters with steel shrapnel."

EXPERIMENTS ON THE EFFECT OF AIR SPACES BETWEEN SHOT AND CHARGE. Numerous statements have been made in the papers in connection with the Thunderer accident on the liability of a gun to burst if the projectile were not rammed home It may be remembered by many that this was at first put forward as the actual cause of the bursting of the 38-ton gun—an explanation which we rejected as insufficient. There was some ground for it; projectiles had been known to slip forward in a gun, so it was stated, when the muzzle was dipped, and nearly everyone who has shot has been warned of the danger of getting the muzzle of a fowling piece plugged up with mud or dirt of any kind. Captain Noble, in his evidence before the Thunderer Committee, points out that this is a very different state of things from the explosion of powder with a space between it and the projectile. A charge of shot passing through a barrel and suddenly checked at the muzzle by such portions of the mud as may not have yet yielded to the action of the exploding gas, more nearly corresponds to the experiment made by Captain Andrew Noble, of firing wax against a bullet held in the muzzle of a rifle barrel. In short, the double loading more nearly resembles the case of a shot-charged fowling-piece with an obstruction in the barrel, than the supposed case of a single shot fired with an air space behind it.

To test the matter fully experiments have been carried out at Elswick with much care. Our service 10-in. gun fires a charge of 70 lbs. with a 400 lb. projectile without gas check. The Elswick 10-in. gun, employed in this trial, fired an 85 lb. charge with a 403 lb. projectile, including gas check in each instance. The air space was successively 2 ft., 4 ft., and 6 ft. in the first three rounds, and as the air space increased, the pressure on the bore and velocity of the shot decreased, the pressure gauges showing that the gun, with 4 ft. air space, was hardly exposed to half the pressure that would have existed had the same projectile and charge been fired when properly rammed home. Considerable confidence had already been shown by the Elswick Company in its conviction that an increase of air space would not strain or injure the gun, but one round was finally fired with rapid burning powder, which would, if the shot were rammed home, give 27 tons to 30 tons pressure on the bore. With an air space of 4 ft., however, only 16.7 tons were registered. This shows that the increase of air space diminishes the explosive effect under such conditions as would exist in the case of a projectile slipping forward, and that the violent strain which fell on the 38-ton gun was due to some other cause, while there is other evidence to point out that the cause actually was double loading.

The gun selected for the experiments was of 20 tons weight and 10 in. caliber, but having its powder chamber enlarged to 12 in. The powder used was a pebble powder, giving, according to the standard furnished by the Gov-

ernment specification, a velocity of about 1480ft. per second, from an 8 in. gun, the pressure developed in the proof gun being within the prescribed limits. The powder was well known, its velocity and pressure having been determined in a great variety of guns.

The charges used throughout were the same as those used in the Thunderer's guns, as was also the length of the cartridge, which was 22 in. Under normal conditions, that is, without vacant space, and with a gravimetric density of .835, or 33.3 cubic inches to the lb., the chamber pressure with the powder has been ascertained to be 17 tons to the square inch; but with a 22 in. length of cartridge this pressure would be higher, about 20 tons to the square inch, and the muzzle velocity given to a 400 lb projectile would be 1487 ft. The first round was fired with a charge of 85 lb. pebble powder, the weight of projectile with gas check being 403 lbs.

Three crusher gauges were placed in the base of the projectile, one as near as possible to the top of the shot, one in the center, and one at the bottom. A crusher gauge was also placed at the bottom of the bore. The crusher gauges used in the first round were, previously to firing, set to 10 tons on the square inch. The vacant space between the cartridge and shot was - ft. No wad was used. On firing, the velocity of the shot was found to be 1240 ft. per second, the pressure at the bottom of the bore 11.7 tons, while the whole of the crusher gauges in the projectile were unaltered—that is, in no case had the pressure on the projectile reached 10 tons per square inch. The second round consisted of a charge of 85 lb. pebble powder, and a projectile of 402 lbs., with a vacant space of 4 ft. In this instance the crusher gauges in the gun and in the center of the base of the shot were set to 10 tons, while those at the top and bottom of the shot were left unadjusted, or to indicate as low a pressure as the material of the crusher would admit of. On firing, the velocity of the shot was found to be 1067 ft. per second; the pressure at the bottom of the bore, 10.15 tons on the square inch; at the top of the shot, 7.6 tons; at center of shot, gauge unaltered—therefore, under 10 tons—and at bottom of shot, 6 tons. The pressures on the shot in both of these cases are less than that due to the density of the exploded products at the point where the shot rested. In other words, there was no increase of pressure due to the run of the gas. No wad was used.

In the next round the projectile and charge were of the same weight and description as in the second round, the vacant space between the cartridge and projectile being increased to 6 ft. A wad of Thunderer pattern was placed in contact with the projectile. On firing, the velocity of the shot was found to be 849.5 ft. per second, the pressure at bottom of bore under 10 tons on the square inch, at the top of the base of the shot under 8 tons, at center of shot 5 6 tons, and at bottom of shot under 8 tons. The following round consisted of a projectile and charge of the same weight and description as before, the vacant space between the cartridge and projectile being 2 ft. A papier-maché wad, Thunderer pattern, was placed 4 ft. in front of the projectile. On firing, the velocity was found to be 1208 ft. per second, the pressure at bottom of bore 11.1 tons, at base of shot, top, 7.9 tons; center, 9.2 tons; and bottom, 8.4 tons. The presence of the wads did not appear to have modified any of the conditions, it certainly did not increase the pressures in either case. A considerable quantity of the material of the wads was picked up within 50 yards from the muzzle. It was split up into thin laminæ and torn into shreds.

The foregoing rounds made it abundantly evident that with pebble powder no pressure capable of endangering the safety of the gun would result. It was then determined to fire a round with a charge of far more rapidly-burning powder than is now used for heavy guns, and which there was little doubt would generate a high local pressure, though not sufficient to injure the gun. The gun was therefore fired with a charge of 85 lb. R. B. G. powder, made up to a length of 22 in. and with a distance between charge and shot of 4 ft.

On firing, the velocity was found to be 1136 ft., the pressure at the bottom of the bore 16.7 tons on the square inch. Those on the base of the shot were as follows: near the top 25.5 tons, in center 35.3 tons, and near the bottom 23.3 tons. Had the gun been fired normally, the pressure in the chamber would have been from 27 to 30 tons on the square inch, and on the shot nearly as much. These exceptional pressures produced no ill effect on the gun.

It will be observed here that there are wide differences in pressures at points but little apart from one another. These differences may be explained by supposing that in the gauges where the higher pressures are indicated the fluid products in larger mass strike the gauge at a high velocity, and the energy of these products reconverted into pressure indicates an abnormally high pressure.—*Engineer.*

BOOK NOTICES

SUPPLEMENT TO A HANDBOOK OF CHEMICAL MANIPULATION. By C. GREVILLE WILLIAMS, F. R. S. London: John Van Voorst. Price $1.00.

This pamphlet of 88 pages is, as its title implies, only a collection of recently devised methods of laboratory operations.

It is purely technical in its style, and of use only to the analytical chemist or physicist, but to such the work is invaluable.

LIFE AND WORK OF JOSEPH HENRY. By FRANK L. POPE, Vice-President of the American Electrical Society. New York: D. Van Nostrand. Price 50 cts.

This brief biography is a reprint from the journal of the American Electrical Society.

It involves of necessity a bit of the history of the development of electrical science in this country.

This dual sketch is exceedingly well, though briefly, presented by the author, who is well known as a ready writer.

The pamphlet is printed on tinted paper and well illustrated.

TREATISE RELATIVE TO THE TESTING OF WATER WHEELS AND MACHINERY. By JAMES EMERSON. Springfield: Weaver, Shipman & Co. For sale by D. Van Nostrand. Price $1.50.

This book is of undoubted value to all who use water-power. There is much practical information relating to Hydraulics, aside from the detailed reports of trials of a large number of American Turbine Wheels.

Probably no such facilities for testing hydraulic motors can be found elsewhere in the world; and it is furthermore unlikely that any other engineer than Mr. Emerson can produce such an array of practical tests personally directed and recorded.

The illustrations of the book represent most of the forms of American Turbines.

THE PLUMBER AND SANITARY ENGINEER. This excellent journal is to appear on the 1st and 15th of each month instead of monthly, as heretofore.

This change, which has been contemplated for some time, has been made necessary by the increasing popular attention given to sanitary subjects, and by the difficulty of printing the current information relating to such subjects in the present limited space.

This journal was founded to remove the public prejudice against modern improvements, and to show that where sickness is ascribed to their use it is because of ignorance, parsimony or dishonesty on the part of those responsible for their arrangement.

ANNUAL REPORT UPON THE SURVEY OF THE NORTHERN AND NORTH-WESTERN LAKES AND THE MISSISSIPPI RIVER. In charge of C. B. COMSTOCK, Major of Engineers, and ROBERT BRIG, General U. S. A., and H. M. ADAMS, Captain of Engineers, U. S. A. Washington: Government Printing Office.

The present issue is an Appendix to the Report for 1878, and exhibits the following extension of the survey:

Progress of the work during the year.—On Lake Erie the triangulation has been carried from Cleveland, Ohio, to the west end of the lake. The topography and hydrography have been extended to include all of the American shore, and the Canadian shore from Detroit River to Point Pelee. A base-line has been measured near Chicago and the connecting triangulation east has been completed to White Pigeon, Mich.

The latitude and longitude of Memphis, Tenn., have been determined, and in connection with Capt. W. S. Stanton, United States Engineer, the longitudes of Fort Laramie, Wyo., Camp Robinson, Neb., and Deadwood, Dak., have been determined.

The survey of the Mississippi River has been carried from Mount City, above Memphis, to Scanlon's Landing, Ark., and a line of precise levels has been completed from Memphis, Tenn., to Austin, Miss.

A chart of Lake Ontario, coast charts Nos. 1 and 2 Lake Ontario, coast charts Nos. 7, 8 and 9 Lake Michigan, and detail charts Nos. 1, 2, 3, 4, 5, 6 and 7 Mississippi River have been completed.

PROCEEDINGS OF THE INSTITUTION OF CIVIL ENGINEERS. Of the excerpt minutes of the above proceedings we have received, through the kindness of Mr. James Forrest, A. I. C. E., the Secretary:

Railway Work in Japan. By Wm. Furniss Potter, M. I. C. E.

Encroachments of the Sea from Spurn Point to Flamboro' Head. By Robert Peckwell. A. I. C. E.

Portland Cement Concrete in Ashes and Portland Cement Mortar. By Charles Colson, A. I. C. E.

Portland Cement Concrete. By John Watt Sandeman, M. I. C. E.

The Construction of High-Pressure Boilers. By James Fortescue Flannery.

The Constructian of Heavy Ordinance. By J. A. Longridge, M. I. C. E.

This last paper is presented with its illustrations in our present issue. The discussions will appear in our next.

TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS. Vol. VI. May, 1877, to February, 1878. Easton: Published by the Institute.

This volume contains the papers presented at the meetings of Wilkesbarre, Amenia and Philadelphia.

From the list of papers, forty-nine in number, we select the following titles as affording an estimate of the range of topics presented:

Hydraulic Mining in California, by A. J. Bowie, Jr.; The Strength of Wrought Iron as affected by its Composition and by its Reduction in Rolling, by A. L. Holley. M.I.C.E.; Manganese Pig, by R. W. Raymond, Ph.D.; Note upon the Blue Process of Copying Tracings, by P. Barnes; On the Manufacture of Artificial Fuel, by E. F. Loiseau; The Mechanical work performed in heating the Blast, by Prof. B. W. Frazier; Copper by Electricity, by N. S. Keith; On Pulverized Zinc and its Uses in Analytical Chemistry, by Dr. Thomas M. Drown; Graphic Method of Keeping the Record of Working of a Blast Furnace, by Wm. Kent, M.E.

The papers alone extend over 560 octavo pages. Many illustrations are interspersed, and there are twelve folding plates.

COLOR BLINDNESS; ITS DANGERS AND ITS DETECTION. By B. JAY JEFFRIES, A. M., M. D. Boston: Houghton, Osgood & Co. Price $2.00.

The interest in the subject of color blindness is becoming wide-spread. Positive knowledge on the subject of this peculiar deficiency of vision is only of recent date. This we believe is the first extended treatise on the subject, and the scientific student is to be congratulated that he is able to get his information from so eminent an authority.

The book will have many readers, and we venture to predict that those who care nothing about the economical aspect of the question will largely outnumber those who do. There is a social side of the subject that will engage the attention of the multitude. Many a person who is of defective color-sight will afford amusement to his or her friends by hopelessly at-

tempting to assort colors in accordance with Prof. Holmgren's suggestions, aided by the chart which is carefully printed in color for a frontispiece.

The typography of the work is good, but any one who can look at the tri-colored cover, without wishing for the moment that he was partially color-blind, should regard the condition of his color-sense with some uneasiness.

A Theoretical and Practical Treatise on the Manufacture of Sulphuric Acid and Alkali. By George Lunge, Ph.D., F.C.S. Vol. I. London: John Van Voorst. Price $14.00. For sale by D. Van Nostrand.

Considering that this book is devoted to a branch of technics, the elegance of its typography and illustrations is altogether exceptional.

This volume (658 large octavo pages) is devoted exclusively to the manufacture of sulphuric acid. How fully the theory and practice of this branch of technology is covered by the author may be inferred from the following titles of the chapters:

Chapter I, Chemical and Physical Properties of the Oxides of Sulphur; II, Analysis of Sulphuric Acid; III, Historical Notes of the Manufacture; IV, The Raw Materials; V, Sulphuric Acid from Brimstone; VI, Sulphuric Acid from Pyrites; VII, The Burner Gas; VIII, The Lead Chambers; IX, Working the Chambers; X, Recovering the Nitrogen Compounds; XI, Theory of the Lead Chamber Reactions; XII, Purification of the Acid; XIII, Concentration of the Acid; XIV, Arrangement of the Apparatus. XV, Yield and Cost of Manufacture: XVI, By-Products of the Manufacture; XVII, Fuming Oil Vitriol and Sulphuric Anhydride; XVIII, Other Processes of Manufacture; XIX, Applications and Statistics.

A Course of Instruction in the Elements of the Art and Science of War. By J. B. Wheeler, Prof. of Military Engineering in the United States Military Academy, and Brevet Colonel, United States Army. New York: D. Van Nostrand. Price $1.75.

Some knowledge of Col. Wheeler's previous efforts in the line of scientific literary labor led us to expect a methodical and carefully arranged treatise, and as complete as the limit of size would permit.

A brief examination of the book leads us to conclude that this expectation is fully realized. The plan of the author, as set forth in the preface, is thus stated:

"History is the basis upon which the principles of the Science of War is founded.

"A correct knowledge of history is only acquired by systematic and methodical study; the study of that part relating to the operations of war should be preceded by a general knowledge of the theory of war.

"The design of this book is to give instructions in the elements of the art and science of war to the cadets of the United States Military Academy, so that they, having acquired a general knowledge of the theory of war, may be able to prosecute systematically and methodically their future studies of military history.

"The plan of the book required brevity and condensation. The constant endeavor has been to state principles and rules intelligently and concisely as possible.

"It may be objected that the different subjects discussed are too cursorily treated; the opposite course would have required volumes.

"The portions of the text relating to the grand operations of war are believed to be in conformity with the views held by the great masters of the art, and are drawn from the writings and expressed opinions of Napoleon, Arch Duke Charles, Frederic the Great, and others.

"The parts relating to minor operations are drawn from many professional works upon these subjects and the Army Regulations of 1863."

The subjects treated by chapters are: Chap. I, Definition of the Art of War; II, Strategy; III, Plan of Campaign; IV, Composition of an Army; V, Marches; VI, Battles; VII, Positions; VIII, Attack of Positions; IX, Defensive Operations; X, Advanced Guards and Outposts; XI, Detachments, Convoys, etc.; XII, Ambuscades and Surprises; XIII, Reconnoissances; XIV, Foraging, Partisans, etc.; XV, Camps, Bivouacs, Cantonments, etc.; XVI, Modern Warfare.

Numerous illustrations are interspersed throughout the text.

Outlines of Field Geology. By A. Geikie, LL.D., F.R.S., &c. London: Macmillan & Co.

It is strange, but true, that although amateur geologists in this country are to be numbered by thousands, field geologists in the true sense of the word are so few and far between, that those capable of making a fairly accurate geological map of their own districts could probably be counted on the fingers. Nor, unfortunately, is this lack of knowledge confined to amateurs, for more than one professor of the science, eminent in certain branches, could be named who look upon the published maps of the Geological Survey as beautiful efforts of scientific imagination, and upon the officers of the Survey as—

Gentlemen of science who ramble round at ease,
And draw their pretty sinuous lines wherever they may please.

To such persons it seems impossible for anyone to follow the outcrop of a bed through all its changing courses across wide stretches of country in which pits or quarries—technically known as *sections*—are rare or absent. Geological maps to most people are complicated puzzels; but, so soon as their significance is realized, they become most valuable aids to the comprehension of the structure of a country.

With the assistance of the beautiful new Ordnance maps, on the scale of six inches to the mile, with contours drawn at frequent elevations, upon which the Geological Survey has recorded its work, the student of physical geography, the engineer, and others can obtain far more information of a district than is often to be acquired from literary productions. Nay, more, a geological map in many cases illustrates the configuration of the surface with more exactitude than most maps convey by

means of shading. The general idea of hill-ranges and mountain-chains derived from the study of ordinary maps is absolutely erroneous. The hideous, crawling, hairy caterpillars that do duty for hill-shading, have to answer for much of the ignorance that prevails concerning the physiography of the world.

The best way of getting to understand geological maps is to learn to make them; and Professor A. Geikie's little work is an admirable guide for the beginner. Until quite recently no work upon field geology has been published in this or any other country. Scattered notices, chiefly by survey officers, had appeared, and two years ago, Mr. Penning, of the English Survey, published an excellent treatise entitled "Field Geology." To this work Professor Geikie's books serves in some sense as an introduction. It appeals, as must of necessity be the case, to those who have some acquaintance already with geology, but is so simple and lucid that it is admirably adapted to the wants of a beginner. Field geology can only be learnt in the open air, and as in most cases teachers have but meager opportunities of exercising their pupils out of doors, this little work will teach them how to observe, and enable them to utilize every country ramble to the utmost advantage.

MISCELLANEOUS.

THE BABYDOM OF MACHINERY.—A lecture having this title was given by Professor Kennedy, of University College, at the rooms of the South London Free Library, Upper Kennington Lane, to an audience consisting chiefly of engineers. Professor Kennedy described the fire drill (by which fire can be obtained by the friction of two pieces of hard wood) as probably the oldest machine known, and as being still in use in some parts of the world. This was developed into a boring drill by the addition of strings and the change of wood for metal, and next into a hand lathe with a bow handle. The potter's wheel was said to be the next oldest machine. Continuous rotation was unknown until about the end of the seventeenth century, all rotation until then having been to and fro. The first known instance of circular rotation was a water-wheel used in Thibet to turn a prayer-mill; though it was also used nearly as long ago in Egypt for purposes of irrigation. The corn mill also is very ancient. The use of the lever is also of great antiquity. The lecture, which was delivered in a very genial manner, and with much humor, was illustrated by the exhibition of some very old books of machinery, mostly written by men of theory only, and they were examined by the audience at the end of the lecture with much interest.

THE Belgian Academy of Sciences lately received a communication from M. Spring descriptive of his experiments in producing solid bodies from their powders by the action of powerful pressure. The results of these experiments, though conducted on the small scale, are both instructive and suggestive of useful applications in the arts. The apparatus employed for the purpose was simply a solid steel prism, having a cylindrical hole perforated in the direction of its axis, and into which the pulverulent substances were placed, then compressed, and more packed in by means of a steel stamper, until the material was packed solidly to almost the level of the surface, and finally subjected to a gradually increasing pressure of about 20,000 atmospheres by means of a screw. The substances operated upon were respectively saltpetre, sawdust of poplar wood, and dry dust of whetstone and of chalk. In the first two cases the resulting mass was perfectly homogeneous and translucent, like porcelain, much harder, more resistant of fracture, and transparent than part of the same substances obtained by fusion. In the case of the sawdust, a block was obtained harder than the wood which furnished it; but its texture was not uniform. It exhibited great stength in the direction of the line of pressure; but at right angles to the action of the pressure the block couid easily be broken. The result in this case, therefore, appeared to be the production of a laminated texture at right angles to the direction of the compressing force. The result with the whetstone powder was unsatisfactory, and also with the dry chalk-dust; but, with slightly moistened chalk-powder, a mass was obtained so firmly compacted that it could not be detached from the apparatus.

PLASTER of Paris has formed the subject of long-continued studies of M. Landrin. whose conclusions were embodied in a recent communication to the *Academie des Sciences*. He finds that the more or less rapid setting of the plaster is due to the mode in which it is burned. Its properties are very different when it is prepared in lumps or in powder. The former, when mixed with its own weight of water, sets in five minutes; while the latter under similar conditions, takes twenty. The reason probably is, that plaster in powder is more easily burned than when it is in lumps, and what tends to prove that fact is, that when the latter is exposed longer than usual to the action of fire it sets more slowly. Gypsum, when prepared at a high temperature, loses more and more its affinity for water, retaining, however, its property of absorbing its water of crystallization. Plaster heated to the red, and mixed in the ordinary manner, will no longer set; but if, instead of applying the ordinary quantity of liquid, the smallest possible portion is used, say one-third of its weight, it will set in 10 or 12 hours, and then it is less porous and becomes extremely hard. To prepare plaster for molding it must be burned slowly for a long time, sufficiently to drive off all its water, and for its molecules to lose a part of their affinity for the liquid. M. Landrin stated that a similar result could be obtained by other means. If the plaster is exposed to the fire of the kiln for a time short enough to allow it to retain 7 or 8 per cent. of its water, it is useless, as it sets almost immediately. If, however, the burning is again resumed, the substance soon loses its moisture, and, if then exposed to the air, it very rapidly retakes its water of crystallization, and then absorption continues more

slowly. It can then be used; it sets slowly, but acquires great hardness.

AMERICAN COMPETITION.—From the report by Consul-General Cowper on the trade of Cuba for the financial year 1877–78 we extract the following with reference to American competition with our manufacturers. When the contest for international trade is so keen, it is necessary that we should seek to ascertain what our shortcomings are, and strive earnestly to remedy them:—The English (says Mr. Cowper) are becoming less and less in the commerce of Cuba each year, and the United States more and more so. Machinery and hardware, in which we were once unapproachable, are falling into the hands of our rivals, the only remnant being a limited import of cutlery and large pieces of machinery, such as steam ploughs, sugar engines, etc.; but even these, from various causes, are now coming from other countries, notably the beautiful machinery from France, such as centrifugal machines, vacuum pans and those connected with distilling. One of the largest imports from England was the large cane knife or machete; some of these are still imported from England, but the fact cannot be, and is not, disguised from the buyers, that these knives are inferior to those made in the United States and in Germany at equal prices, the only advantage possessed by the English article is superiority of polish; hence the increase of the import from England. Take the English plough; it has no chance against the American; for not only is the latter one-third cheaper, but the American manufacturer makes a study of the island of Cuba, and his plough is consequently perfectly adapted to its requirements. So with heavy machinery on sugar estates; the planters find that, as a matter of course, an article whose prime cost is less, which has less freight to pay, and which is made expressly to suit the island, is preferable to the English one, which does not possess these advantages. In railway plant also the Americans are beating us, for the same objection is raised to the English manufacturers; rails, for instance, of the section required here, have to be rolled expressly in England, so that the purchaser has to give his orders four months in advance, whereas in the United States he finds his rails ready for immediate shipment, and cheaper into the bargain.

ASPHALT AND TIMBER FLOORS.—A curious method of laying down floors has been adopted in France, and is said to have obtained a wide application. It consists in putting down flooring, not as hitherto, on joists, but in embedding the boarding in asphalt. The new floors are used mostly for ground stories of barracks and hospitals, as well as churches and courts of law. Pieces of oak, usually 2¼ to 4 inches broad, 12 to 30 inches long, and 1 inch thick, are pressed down into a layer of hot asphalt not quite half an inch thick in the well-known herring-bone pattern. To insure a complete adhesion of the wood to the asphalt and obtain the smallest possible joints, the edges of the pieces of wood are planed down, beveling towards the bottom, so that their cross-section becomes wedge-like. Nails, of course, are not necessary, and a perfect level surface may be given to the flooring by planing after the laying down. The advantages of this flooring, which only requires an even bed on which to rest, are said to be the following:—

1. Damp from below and its consequence, rot, are prevented.
2. Floors may be cleaned quickly and with the least amount of water, insuring rapid drying.
3. Vermin cannot accumulate in the joints.
4. Unhealthy exhalations from the soil cannot penetrate into living-rooms. Asphalt being impermeable to damp, rooms become perfectly healthy even if they are not vaulted underneath. In buildings with several stories, as in hospitals, the vitiated air of the lower rooms cannot ascend, an object which it has hitherto not been possible to attain by any other means.
5. The layer of asphalt will also prevent the spreading of fire from one floor to another in case of conflagration. The flooring here described has been laid in the numerous casements of the newly-constructed forts round Metz, to the satisfaction of the authorities. The cost is about a shilling per square foot. This estimate, somewhat high, would be much lower in districts where oak and labor are cheaper, and the distance from the places of construction less, and especially where there is more competition among contractors than at Metz; and the cost for larger undertakings may be reduced to eight shillings per square meter.

M. DE CHANCOURTOIS, Professor of Geology at the School of Mines in Paris, has been making some experiments bearing upon the mechanism of production of mountain elevations and of valleys, in accordance with the modern theory, as to the cause of the formations by crumplings in the crust of the globe while in a soft and plastic condition. M. de Chancourtois represents the globe by an india-rubber ball, which takes the place of the terrestrial nucleus in fusion, destined to contract on cooling, and, by its shrinking, to produce on the surface the elevations and depressions which constitute the mountains and valleys of the existing earth. That sphere is fitted at one part with a copper tube, provided with a stop-cock, through which the ball is inflated. It is then dipped in a bath of melted wax, and when that has partially set, a small portion of the air is allowed to escape by the tap. The surface of the sphere then contracts slightly and sinks in portions, wrinkling the wax. When a little more air is allowed to escape, those slight wrinkles become more distinct and form ridges and hollows, precisely analogous to the ranges of hills and valleys on the face of our planet. Their relief is, relatively, twenty or thirty times as great as those of the highest mountains on the earth. That difference must be attributed to the fact that the contraction of the india-rubber ball is much greater than the shrinking of the fluid nucleus necessary to determine a crisis of risings on the globe. Less evident effects could easily be produced, but they must always be exaggerated on a small sphere where the highest mountains of the earth are only repre-

sented by projections not exceeding one-tenth of a millimetre. M. de Chancourtois lately presented to the Academy of Sciences two of these balls, one in the first stage of operation, and the other in the second or final one, and they excited great interest among the *savans*.

REYNIER'S ELECTRIC LAMP.—In reference to this lamp, M. de Parville makes the following observations in the *Bulletin Francais*:—"With four Bunsen elements we have just seen a very pretty electric light produced. The elements, which can be charged in five minutes, may be stowed away in a corner, in the cellar, &c., and one may be certain of having, during three or four hours, a splendid, vivid, and at the same time—if it be sifted through a suitable globe—a soft and rosy light. This is evidently an important step taken in the difficult problem of the electrical illumination of apartments and small workshops." Let us give a brief description of the new system: "When a platinum wire is interposed in the circuit of a battery, it may be sufficiently heated to emit a white light. If the wire be replaced by a thin rod of gas carbon, this also may be heated so as to produce a dazzling light. Such is the principle of the electric lamps acting by incandescence, of which various forms, more or less practical, were shown in Paris some years ago. A young electrical engineer, M. Reynier, has hit upon the idea of dispensing with all these complications, and of simply allowing the carbon to be consumed. The carbon, raised to a red-white heat by the electric current, is consumed by oxidation like the wick of a lamp; but its cost is not so great as to prevent its being replaced in the same manner. Thus is obtained an extremely simple electric lamp, which is managed with the same facility as an ordinary lamp. If much light is required the wick is turned up, *i. e.*, the heated portion of carbon rod is augmented; if less light is needed, the wick is turned down. If the lamp is to be extinguished, the circuit is broken; if it is to be re-lit, a knob is turned, and the light flashes forth. Nothing can be simpler. The system is quite elementary. A rod, or rather a needle of carbon, from twenty to thirty centimeters long, and from one to two millimeters thick, is held at one end by a metal rod, which tends to descend by its own weight, and at the other by a carbon wheel in a vertical position. The carbon rod is pressed strongly, whatever may be the consumption of the material, against this wheel, which is made to turn slowly. The current raises the carbon to a white heat at the point of contact of the extremity of the rod with the carbon wheel. The expenditure for charcoal is about 10 centimes per hour. Thus, a rod costing 30 centimes (3d.) will last for three hours, and without any magneto-machine, or steam engine; but with a little battery of four to six elements, anyone can have the electric light in his own home. The lamp which we saw in action is to be perfected with the least possible delay.

THE STRENGTH OF DIFFERENT THICKNESSES OF MORTAR JOINTS.—In No. 31 of "Professional Papers on Indian Engineering," edited by Major A. M. Brandreth, R. E., particulars are given of some experiments made at Narora, Lower Ganges Canal, on the strength of different thicknesses of mortar joints, by Lieut. E. W. Cresswell, R. E.

The different thicknesses of mortar joints to be tested were $\frac{1}{16}$ in., $\frac{1}{2}$ in., $\frac{1}{4}$ in., $\frac{1}{8}$ in., $\frac{3}{4}$ in. A level site close to the weir-sluices was selected (as the blocks of brickwork were afterwards to be put into the talus of that work), and five rows of brickwork bars built, 15 ft. × 2 ft. 6 in. × 2 ft. 6 in., each row containing ten bars, and numbered A to E. Mortar joints in row A were all $\frac{1}{16}$ in., in row B $\frac{1}{2}$ in., and so on, in order mentioned above, row E being $\frac{3}{4}$ in. The foundations for these bars were made 1 ft. deep. The center 10 ft. portion of the foundations being of bricks laid in mud, the end 2 ft. 6 in. portions of bricks laid in mortar, a thin layer of mud was spread over the whole surface of the top of foundation, so that there might be no adhesion whatever between the superstructure and the foundations.

The bricks were sand-moulded kiln-burnt, were carefully gauged and sorted, so that each bar might be built with the required joint, and still the total dimensions of bar as directed be attained. The mortar used was two parts steam ground coal-burnt kanker lime to one part sand, mixed with water in a country bullock "chakki." The joints in every direction were carefully kept of the required thickness, and English bond was employed. The bars were all completed in August, 1877.

In May and June, 1878, the brickwork of the central 10-ft. portion of the foundation was removed, and the bars were simply supported at both ends by the 2 ft. 6 in. pillars. In order to break the bars two stone slabs 2 ft. 6 in. × 6 in. × 6 in. were placed 1 ft. apart on the top of the brick-work and equi distant from the center of the bar. Across these 24 ft. rails were laid, and over these other rails, till the load caused the bar to break across. The line of rupture varied, but was always somewhere between the slabs of stone. It was observed that the average breaking-weight required was greatest in the row C, or of bars with $\frac{1}{4}$ in. joint; this average diminished slightly for the $\frac{1}{2}$ in., and was less again for the $\frac{1}{16}$ in. joint. The thick joints $\frac{1}{2}$ in and $\frac{3}{4}$ in. gave very poor results, the average breaking-weight being about two-thirds of that for the $\frac{1}{4}$ in. joint. The bar that gave the highest result was No. 4 B of the $\frac{1}{4}$ in. joint. The general result appears to be that $\frac{1}{4}$ in joint makes the strongest work, and should be employed in preference to the finer joints.

We may add to the foregoing that if a longer period of time has been allowed to elapse before the trial, the $\frac{1}{2}$ in. and $\frac{3}{4}$ in. joints might possibly have given better results.

THE large hydraulic crane, built especially on a new iron pier at the Woolwich Arsenal to lift the 80-ton guns, is being strengthened to lift the 100-ton guns purchased from Elswick. The frequency with which heavy loads are dropped at Woolwich through the breaking of slings and other such lifting gear, suggests the necessity of exercising a little more care in the selection of these, and the mode of, and the men using them.